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Apple Pollination Studies In Ohio

Freeman S. Howlett

OHIO
AGRICULTURAL EXPERIMENT STATION
Wooster, Ohio

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Apple Pollination Studies in Ohio

Freeman S. Howlett

SUMMARY AND CONCLUSIONS

The results obtained from apple pollination studies in Ohio during the years 1924-1926, inclusive, are presented. The larger part of the data are concerned with the fruitfulness of several varieties when self-pollinated, their effectiveness as pollinizers, and their fruitfulness as female parents in various crosses. These varieties were Baldwin, Delicious, Ensee, Golden Delicious, Grimes Golden, Jonathan, McIntosh, Nero, Northern Spy, Ohio Nonpareil, Rhode Island Greening, Rome Beauty, Stayman Winesap, and Wealthy. Limited data are given with respect to the effectiveness as pollinizers of Banks (Red Gravenstein), Gallia Beauty, San Jacinto (Wilson Red June), and Yellow Transparent, and to the fruitfulness of Oldenburg and Yellow Transparent as the female parents in various crosses.

The trees used in the experiments were growing in the Experiment Station orchards at Wooster and in the Bingham orchards at Hamden, Geauga County, Ohio.*

The results have been obtained not only from hand pollinated flowers subsequently covered with "glassine" bags (1924-1926) but also from flowers left uncovered after emasculation and pollination (1926). In 1926 at Wooster a tree each, of the varieties Baldwin and Golden Delicious, was enclosed separately under a muslin frame with a hive of bees. The Baldwin tree was self-pollinated by the bees. Baldwin flowers were placed under the frame with the Golden Delicious tree to provide pollen with which the bees could cross-pollinate the Golden Delicious flowers.

Two of the more important points emphasized in the literature review are:

1. Altho the data in the literature indicate that apple varieties may occasionally differ in the degree of self-fruitfulness in different localities, similar results obtained by various investigators have often not been followed by similar interpretations.

*The writer is indebted to Dr C A Bingham, owner of the Hamden Orchards, and Mr H A Ingerson, manager, for many courtesies extended during the entire three years' work To these men thanks are extended for the privilege of making the experiments and for their very hearty cooperation.

2. Several of the differences which appear in the literature in the degree of self-fruitfulness of a variety are not as closely correlated with differences in the normal climatic and approved cultural conditions in different localities, as is sometimes considered.

RESULTS OF EXPERIMENTS

Fruitfulness of Varieties When Self-Pollinated

1. No one of the varieties used was sufficiently self-fruitful to warrant being planted in locations where it would be left largely to self-pollination.

2. Altho Baldwin, Delicious, Grimes Golden, and Rome Beauty were the only varieties which produced fruits from self-pollinated flowers, it is concluded that the other varieties under orchard conditions will also produce some fruits from selfed flowers.

3. The results obtained from the Baldwin tree enclosed under a frame with bees were not entirely in agreement with those obtained from the flowers self-pollinated by hand. The highest set ever obtained from Baldwin flowers selfed by hand was 2.6 percent. The tree enclosed with the frame had a set of 7.4 percent after the first drop and of 6.0 percent at harvest.

4. In view of the consistent failure of Baldwin flowers selfed by hand, both bagged and left exposed, to produce sufficient fruits to yield a commercial crop, Baldwin is considered not to be sufficiently self-fruitful to justify the recommendation that it be planted in locations where it must be largely self-pollinated.

5. No arbitrary classifications were made dividing the varieties which were not sufficiently self-fruitful to yield commercial crops into self-unfruitful and partially self-fruitful groups.

6. Altho it is probable that the Delicious, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap have a lesser degree of self-fruitfulness than the Baldwin, Grimes Golden, Jonathan, Rome Beauty, and Wealthy, at least one other factor appears to be concerned which accentuates this difference.

7. No evidence was obtained justifying the conclusion that Baldwin, Grimes Golden, Jonathan, Rome Beauty, and Wealthy are significantly different in degree of self-fruitfulness.

Effectiveness of Varieties as Pollinizers

1. Delicious, Ensee, Golden Delicious, Grimes Golden, Jonathan, McIntosh, Northern Spy, Rome Beauty, San Jacinto, Wealthy, and Yellow Transparent were effective pollinizers for all

varieties upon which they were used. Gallia Beauty was an effective pollinizer for Stayman Winesap but was of little value on Rome Beauty in 1925 and 1926.

2. Baldwin, Banks, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap were not effective pollinizers for any variety upon which they were used. They did, however, occasionally produce small percentages of set, indicating that under orchard conditions some fruits will develop even tho satisfactory commercial crops will not be produced.

3. There was a positive correlation between the effectiveness of the varieties as pollinizers and their pollen germination. The pollen of the varieties listed as effective pollinizers gave high percentages of germination and long pollen tube growth. The pollen of Baldwin, Banks, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap in no case germinated more than 7 percent (usually less) on agar-sugar media. Moreover, the pollen tubes which were produced were short, thick, and soon burst.

4. No definite examples of physiological cross-incompatability were found.

5. The failure of Baldwin, Banks, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap, as pollen parents, to produce fruits are examples of cross-sterility, intersexualism, due to impotence of pollen.

Fruitfulness of Varieties as Female Parents

1. Baldwin, Ensee, Golden Delicious, Grimes Golden, Jonathan, McIntosh, Northern Spy, Oldenburg, Rome Beauty, Wealthy, and Yellow Transparent gave relatively high percentages of set when cross-pollinated with varieties listed as effective pollinizers.

2. Delicious, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap gave rather unsatisfactory results as female parents when cross-pollinated with effective pollinizers. This appears in part to be an expression of the fact that a considerable number of the flowers of these varieties are unable to set fruit regardless of the pollinating variety used. These varieties under normal orchard conditions may have sufficient flowers capable of setting fruit so that satisfactory commercial crops are produced

3. It is suggested that the crosses in which Delicious, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap are used as female parents and fail to give satisfactory percentages of set with effective pollinizers are also examples of partial cross-sterility, intersexualism.

Results With Methods of Self- and Cross-Pollination

1. Bagging the flowers after self- and cross-pollination did not appear to reduce the set when compared with the flowers left without covering.

2. Emasculated flowers left uncovered following cross-pollination failed in a number of cases to give as high percentage sets as emasculated bagged flowers. This is possibly due to drying of the pistils and indicates the desirability of eliminating emasculation from pollination procedure wherever possible.

3. The self-pollinated flowers on the tree enclosed under a frame with bees and repeatedly pollinated by bees gave a higher percentage set than ever obtained from hand pollinated flowers on open pollinated trees. Such a difference is possibly due to different nutritional conditions of the flowers under the two methods.

4. In determining the degree of self-fruitfulness of a variety the use of the tree method, in which all the flowers of the tree are selfed, does not so nearly approach orchard conditions as is sometimes assumed.

5. Great care is necessary in interpreting orchard observations and surveys carried on to determine the degree of self-fruitfulness of a variety.

6. The results obtained from the flowers emasculated and left without covering give no indication that apple pollen is borne by the wind. Moreover, celluloid strips covered with vaseline and exposed in the orchard caught no pollen.

INTRODUCTION

Pollination studies with the apple have been carried on by a number of investigators in several states and countries during the last thirty-five years. The problem soon became of considerable interest even tho the commercial bearing orchards contained several varieties. Altho many varieties have been subsequently shown to have a low degree of self-fruitfulness there has been little reason to suppose that a lack of adequate pollinating varieties has been a limiting factor for satisfactory fruit setting in the majority of these older orchards.

However, in late years the number of varieties planted in orchards has been limited. In some instances large blocks of one or two varieties have been planted in which there is danger that the set of fruit may be limited occasionally, if not consistently, by inadequate pollination.

The orchardist desires some assurance at planting time that inadequate pollination later will not limit the set of fruit. He wishes to be reasonably certain that he has a sufficient number of trees of an effective pollinating variety and that, in turn, this variety will be well pollinated. Accurate information as to the fruitfulness of a variety if planted in a location where it must largely pollinate itself as well as to the relative value of certain commercial varieties as pollinizers is necessary. With this knowledge, a grower can make a satisfactory planting arrangement with the varieties desired.

The data presented in this bulletin are concerned with the fruitfulness of a number of apple varieties when self-pollinated, their effectiveness as pollinizers of other varieties, and their fruitfulness as female parents in various crosses.

DEFINITION OF TERMS

Before reviewing the literature it seems desirable that the meaning of the terms *self-sterility, self-fertility, self-unfruitfulness,* and *self-fruitfulness* as used in this bulletin be clearly understood.

The distinction made by Kraus (47)* and others in the use of terms afforded a more accurate differentiation of the facts. *Self-sterility* is used to define the inability of a plant to produce fruit

*Reference is made by number to literature cited, page 81

with viable seeds when self-pollinated. The term has been commonly used in horticultural literature to apply to the inability of a plant to produce fruit, without reference to the viability of possible seeds within such fruit. *Self-unfruitfulness* refers to the condition when no fruit is produced. *Self-fertility* has been quite commonly used to mean the ability of a plant to produce fruit following self-pollination with no reference to the presence of seeds or their viability, if present. However, the term more accurately applies to the ability of a plant to produce mature fruit with viable seeds as a result of self-pollination. *Self-fruitfulness* refers to the ability of a plant to produce mature fruit either without pollination or when pollinated by its own variety. This definition of self-fruitfulness makes no distinction between fruits which have developed with seeds, those which have developed in consequence of fertilization, even tho embryo abortion occurred shortly thereafter, and those which may have developed even without fertilization in any ovules. A variety of fruit may thus, theoretically, be self-fruitful and also self-sterile.

LITERATURE REVIEW

Auchter (2) gave an excellent review of several phases of pollination problems, and Chandler (11) presented in tabular form the results of investigations on the more common apple varieties grown in this country. However, the writer feels that a more comprehensive presentation of the results obtained with the same varieties used in this study as well as a discussion of several phases of pollination procedure is justified.

In this review the writer has attempted to arrive at a possible explanation and interpretation of some points of apparent disagreement. It is fully realized that such studies have been undertaken by several investigators working in regions where the various climatic factors, such as seasonal rainfall, temperature, and humidity are both alike and unlike. Moreover, the cultural practices under which the trees were growing, as well as the pollination methods, have not always been similar.

The data obtained from the same variety have not always agreed. Variations have been noted in different localities between the results of a variety when self-pollinated or when used in crosses. It is usually concluded that different results from self-pollinated flowers are due to differences in the approved cultural and normal climatic conditions under which the trees of the variety concerned are growing in the various localities. The writer

believes that discordant results are often due to other factors, such as differences in pollination procedure. The fact also deserves emphasis that similar data have not always led to similar interpretations.

In order to clarify the data as well as to evaluate the importance of the factors involved, the literature concerning the varieties used in this study has been discussed under the following heads: (1) fruitfulness of the varieties when self-pollinated, (2) effectiveness of the varieties as pollinizers of other varieties, and (3) fruitfulness of the varieties as female parents in various crosses.

It is essential that the fruitfulness of a variety when used as the female parent, in addition to its effectiveness as a pollinizer for other varieties, should be clearly understood. More attention must be given in the future to the response of a variety when pollinated by an effective pollinizer, if examples of partial or complete cross-sterility are not to be considered examples of physiological cross-incompatibility as defined by Stout (68).

FRUITFULNESS OF VARIETIES WHEN SELF-POLLINATED

Several of the varieties used in this study have been considered to vary in self-fruitfulness to a greater degree and wider range than is justified by a critical study of the literature. In order to give a more accurate conception of the extent and range of self-fruitfulness, the evidence from the varieties used in this study has been presented in considerable detail. The writer does not deny, however, that differences in the degree and range of self-fruitfulness of varieties *do* exist.

BALDWIN

Some controversy has recently arisen in regard to the degree and range of self-fruitfulness of Baldwin. One group of investigators have presented evidence to indicate that it is practically self-unfruitful, while a second group have obtained sufficient fruits from selfed flowers to give a satisfactory commercial crop. Still a third group have considered its self-fruitfulness established from orchard observations.

The results obtained by the first group indicate a considerably greater range over which Baldwin has given unsatisfactory results when self-pollinated, than is commonly thought. Altho Waite (75) stated that Baldwin was as nearly self-fruitful as any variety, he added that it was far from being entirely so and that some of the trees used in his experiments seemed to be self-unfruitful. He

reported that the percentage set of fruit resulting from self-pollination was not more than one quarter of that obtained when the variety was cross-pollinated. Moreover, the fruits resulting from self-pollination were one-fourth to two-thirds the size of those resulting from cross-pollination and were seedless.

Waugh (76) in two years' work in Vermont obtained 1 fruit from 169 bagged flowers. Altho Lewis and Vincent (52) in Oregon classified Baldwin as self-fruitful, out of a total of 200 bags they obtained only 5 fruits from the hand-pollinated flowers and 9 from the bagged flowers. Since the text indicates that all flowers of the clusters were included, the set from 1000 to 1200 flowers was not higher than 1.4 percent. Gowen (32) in Maine reported that 35 clusters out of 40 had no fruit. Since all flowers of each cluster were selfed, the percentage set was also relatively low. Morris (60) in Washington obtained a 1.48 percent set from 534 flowers. Auchter (2) stated that Baldwin is only partially self-fruitful in Maryland, altho the percentage set was not given. Sax (67) in Maine reported that the variety is self-unfruitful. In 1920 he obtained 0.9 percent set from 1754 flowers while no fruits developed either from 126 flowers in 1921 or from 70 in 1922. Data are given in Table 1 taken from Vinson (73) with reference to a Baldwin and a Stayman Winesap tree enclosed with a hive of bees under a muslin frame. The set from 7338 flowers on the Baldwin tree was 4.9 percent. In view of the fact that Stayman Winesap has been generally shown to be of little value as a pollinizer, a considerable number of these fruits probably developed from self-pollinated flowers, altho it is doubtful if this percentage set can be considered a satisfactory commercial crop.

Data indicating a relatively low degree of self-fruitfulness of Baldwin have thus been obtained in such widely separated localities as Maine, Vermont, and Washington. However, the evidence does not justify the conclusion that no fruits whatever are produced from selfed flowers in these localities where the variety has not been sufficiently self-fruitful to yield a satisfactory commercial crop.

On the other hand, some data in the literature indicate that Baldwin flowers, under certain conditions, may be sufficiently self-fruitful to give a fairly satisfactory commercial crop. Corrie (15) in England stated that "many" selfed flowers of Baldwin gave 116 fruits, some of which had no seeds. Keil (45) in Ohio reported 5 fruits set from 80 flowers. McDaniels (55) at Ithaca, New York, enclosed two dwarf Baldwin trees six years old under a frame

covered with mosquito netting and introduced bees into the cage. On tree 1, 10.7 percent of 420 flowers set fruit and on tree 2, 12.1 percent of 720 flowers. Two check trees, exposed to open pollination gave 5.9 and 12.3 percent set, respectively. Overholser (61) in California obtained 7.1 percent set from 209 flowers, altho the normal set of open pollinated flowers was 19.8 percent.

Data indicating a greater degree of self-fruitfulness have thus been obtained in New York as well as in such widely separated localities as England and California.

It has been stated by a third group that orchard observations support the conclusion that Baldwin is sufficiently self-fruitful to give a satisfactory commercial crop. In this connection Gardner, Bradford, and Hooker (29) stated that the heavy production characterizing large blocks of Baldwin is sufficient evidence of the self-fruitfulness of the variety. Chandler (11) concluded that experience in the orchard with Baldwin agrees with the results of pollination studies and indicates that the variety is self-fruitful. However, there are two reasons precluding the acceptance of these conclusions. In the first place, observations by others do not agree that the variety is sufficiently self-fruitful to yield commercial crops. Beach (8) in New York stated that Baldwin is more fruitful in mixed blocks of several varieties than in solid blocks of Baldwin alone. Altho Fletcher (27), also from New York, stated that the variety is exceptionally self-fruitful when planted in solid blocks, he added later that in mixed orchards it is uniformly more fruitful than when planted in large blocks.

The most important objection to the acceptance of orchard observations as evidence in favor of satisfactory self-fruitfulness of this variety lies in the fact that no results are available from carefully planned and executed surveys. Only after surveys, continued over several years, in which the certainty of fruitfulness of large blocks of Baldwin with no intermixed varieties, and with no closely adjacent orchards of other varieties, has been observed, are we justified in concluding from evidence of this nature that Baldwin is sufficiently self-fruitful.

The self-fruitfulness of Baldwin appears to vary from a degree in which insufficient fruits are developed to a degree in which at least a fairly satisfactory commercial crop is produced. It does not seem likely to the writer that these variations are due to differences in the normal climatic and approved cultural conditions in various localities. That they are due to particular seasonal factors seems open to question. It appears to the writer that another factor is responsible for the variations observed.

DELICIOUS

There is little disagreement in the results obtained from experiments designed to indicate the degree of self-fruitfulness of Delicious. Several investigators (72, 60, 16, 21, 3, 33, 61, 64, 53) reported few or no fruits developed from selfed flowers. However, Dorsey (21), Haber (33), and Auchter (3) also reported that Delicious flowers did not set satisfactorily when pollinated by varieties which are generally considered effective pollinizers. Recently Whitehouse and Auchter (77) obtained satisfactory sets of fruit from cross-pollinated flowers on a Delicious tree whose selfed flowers gave only a slight percentage set.

GOLDEN DELICIOUS

Golden Delicious was so recently introduced that only limited data in regard to its degree of self-fruitfulness are available. Auchter (3) and Lewis (53) reported that the variety has a very low degree of self-fruitfulness.

GRIMES GOLDEN

Grimes Golden has been classified in the literature as self-unfruitful, partially self-fruitful, and self-fruitful, upon the basis of considerable data, which the writer does not believe to be significantly different. The classification of the variety as partially self-fruitful as opposed to self-unfruitful has been occasionlly based upon the development of a few fruits. Moreover, the confusion of partial self-fruitfulness with self-fruitfulness has also followed in consequence of different interpretations given to data which do not appear to be significantly different.

Altho several investigators (63, 70, 45, 16, 53) obtained no fruits from selfed flowers of Grimes Golden, there is little justification to assume that under orchard conditions no fruits whatever would be formed from selfed flowers. Morris (60) obtained 1.47 percent set from 1284 bagged flowers of Grimes Golden.

The classification of Grimes Golden as partially self-fruitful and self-fruitful upon the basis of similar data is obvious when the results obtained by the various investigators are compared. Lewis and Vincent (52) classified the variety as self-fruitful, altho they obtained only 11 apples from 100 clusters of flowers bagged and hand pollinated, and 3 from 100 clusters of flowers covered with bags but not hand pollinated. Since all flowers of the clusters were pollinated, the set from the 500 to 600 flowers was evidently less than 3 percent. Wicks (78) obtained 29 percent set from 100

flowers in 1915, 0.78 percent from 256 flowers in 1916, and 7 percent from 86 flowers in 1917. He stated in conclusion that the "data show the necessity of cross-pollination" which indicates that he did not consider the variety sufficiently self-fruitful to give a commercial crop. Vincent (72) classified Grimes Golden as partially self-unfruitful upon the basis of data similar to those given by Lewis and Vincent (52) and not significantly different from those given by Morris (60). In 1911, 2.3 percent developed from 683 flowers; in 1912, 5.2 percent from 1485 flowers; and in 1914, 1 percent from 365 flowers. In 1912 he also obtained 1.7 percent from 8232 flowers on a tree enclosed with bees under a muslin frame. Auchter (2) classified the variety as self-fruitful despite the fact that the set from 661 flowers bagged but not hand pollinated was 1.66 percent and from 662 flowers hand pollinated and bagged 0.15 percent. In 1924 (3) he reported some fruits set from half of a Grimes Golden tree enclosed with half of a Stayman Winesap tree under a frame with bees excluded.

It is thus evident that the variety Grimes Golden has been occasionally classified as partially self-unfruitful, and self-fruitful upon the basis of considerable evidence which does not vary beyond the probable range of experimental error. There seems little justification for Chandler's (11) conclusion that "in a good many climates the variety is self-fruitful to a satisfactory degree". Altho there is little justification to assume that the variety is absolutely self-fruitful in any locality, the data do not warrant the conclusion that the variety is self-fruitful to a sufficient degree in any locality to give a satisfactory commercial crop.

JONATHAN

Jonathan has been considered to vary more widely in the degree of self-fruitfulness in various localities than is justified from the data available. Several investigators (52, 60, 33, 16) obtained no fruit from selfed flowers. Wicks (78) obtained 10.11 percent set in 1915 from 168 hand pollinated flowers, but in 1916 and 1917 no fruits set from any of the selfed flowers. His conclusion that the data "show the necessity of cross pollination" indicates that he did not consider the variety sufficiently self-fruitful. Vincent (72) in 1911 obtained 1.3 percent set from 388 bagged flowers and in 1912 4.8 percent from 1788 flowers, as compared to 2.9 percent set from 15,588 flowers on a tree enclosed under a frame with bees. In 1914, 1317 bagged flowers set 1 percent at Lewiston, Idaho, and 48 flowers set 2.8 percent at Moscow. On the basis of these results

he also classified the variety as partially self-fruitful. Dorsey (21), using three dwarf trees, obtained 2.1 percent set from 188 flowers. Auchter (2) stated that Jonathan is partially self-fruitful, but the percentage set was not given. Hutson (43) obtained 0.8 percent set from 1985 flowers of Jonathan enclosed under a frame with a Wealthy tree but with insects excluded. Overholser (61) obtained 1 fruit from 600 selfed Jonathan flowers.

These data do not indicate that Jonathan varies in its degree of self-fruitfulness in different localities beyond the probable range of experimental error. Jonathan, similar to Grimes Golden, does not appear to have a sufficiently high degree of self-fruitfulness. There is no justification to assume, however, that the variety under orchard conditions will set no fruits from selfed flowers.

McINTOSH

The greater part of the data are in agreement that the McIntosh is not sufficiently self-fruitful to give a satisfactory crop. Several investigators (54, 30, 72, 32, 16, 2, 67, 55) reported few or no fruits from selfed flowers.

On the other hand, Morris (60) reported 8.8 percent set from 365 selfed flowers. Macoun (57, 58) presented contradictory results from his pollination experiments. The disagreement between the data reported in 1924, using two different methods suggests that some unknown factor may be responsible.

NERO

Nero has been reported (63, 14, 2) to be self-fruitful to a very low degree. The problem of determining the degree of self-fruitfulness has been complicated as in the case of Delicious by the failure of a very large proportion of the open pollinated flowers to set fruit (63, 14).

NORTHERN SPY

Several investigators (76, 72, 60, 67, 32) obtained no fruits from selfed flowers.

RHODE ISLAND GREENING

Rhode Island Greening is generally considered not to be sufficiently self-fruitful. This view has been largely based upon data from hand pollinations. Of late the occasional abnormal behavior of the variety in the orchard has also been cited as evidence indicating its very low degree of self-fruitfulness.

The evidence from the hand pollinated flowers is in close agreement that few fruits develop from selfed flowers. (75, 76, 52, 72, 32, 16, 67, 69, 61).

Under certain conditions Rhode Island Greening has been observed to drop such a large number of flowers and partially developed fruits that unsatisfactory crops were produced. In this connection Chandler (11) and McDaniels (56) stated that when the weather conditions are very unfavorable for insect activity, the variety may set very lightly, while Baldwin, for example, sets heavily. They pointed out the importance of this fact in indicating the self-unfruitfulness of the variety. Altho this failure to set satisfactory crops might be so accounted for, other factors may be involved. Evidence obtained from pollinating Rhode Island Greening flowers (75, 67) suggests the probability that a considerable number of flowers cannot set fruit even when pollinated by effective pollinizers.

ROME BEAUTY

Rome Beauty, like Grimes Golden, has been classified as self-unfruitful and partially self-fruitful upon the basis of considerable data which do not appear to be significantly different when the experimental error is considered.

Altho several investigators (52, 54, 45, 53) obtained no fruit from selfed flowers, there is little justification for assuming that the pollination of a larger number of flowers would have failed to produce any fruits. Alderman (1) obtained 1.01 percent set from 10,730 flowers on a tree under a frame, and 1.36 percent from 658 hand-pollinated flowers. The summary of his work with Rome Beauty showed 1 percent set from 16,826 selfed flowers. Vincent (72) obtained no fruits from the hand pollinated flowers in 1911 and 1914 at Moscow, Idaho. At Lewiston, in 1914, 0.83 percent developed from 240 selfed flowers. In 1912, 6871 flowers on a tree under a frame gave 5.7 percent set; while 2418 bagged flowers in the same year set 3.0 percent. On the basis of these results, he classified the variety as partially self-fruitful. Morris (60) obtained 1.6 percent set from 472 flowers in one orchard and no fruits from 491 flowers in another. Crandall (16) classified Rome Beauty as self-unfruitful after obtaining only one fruit from a considerable number of selfed flowers. Auchter (2) stated that the variety is self-fruitful in Maryland, but he gave no data in regard to the percentage set.

It is thus evident that the data from widely separated localities indicate that the degree of self-fruitfulness is not sufficient to give a satisfactory commercial crop. Undoubtedly, however, Rome Beauty will produce some fruits from selfed flowers.

STAYMAN WINESAP

The data indicate that this variety is self-fruitful to a very slight degree only (62, 63, 14, 72, 16, 21, 2, 73). Stayman Winesap, like Delicious, gave relatively small percentages of set when pollinated by varieties with pollen of high germinability. This fact has complicated the problem of determining the approximate degree of self-fruitfulness.

WEALTHY

Wealthy, like Baldwin and Grimes Golden, has been considered to vary decidedly in its degree of self-fruitfulness. It has been classified by some investigators as absolutely self-unfruitful in consequence of the failure of any fruits to develop from selfed flowers. Other investigators, upon the basis of the development of a few fruits, have classified the variety as partially self-fruitful. Still others have considered the variety self-fruitful, either on the basis of results from hand pollinations or from orchard observations.

Altho several investigators (76, 52, 12, 13, 21, 45) obtained no fruits from selfed flowers, there seems little justification for assuming that no fruits under orchard conditions will develop from selfed flowers. In this connection Logsdail (54) obtained 4.6 percent set at the first count from selfing 172 flowers with dry pollen and 1.3 percent from 72 flowers selfed with fresh pollen. No fruits remained at harvest time. Vincent (72) after obtaining 2.2 percent from 216 flowers in 1914, classified the variety as partially self-fruitful. Morris (60) obtained 0.5 percent set from 647 selfed flowers. Auchter (2) classified Wealthy as self-fruitful upon the basis of data not significantly different from that of Vincent (72). He obtained 4.5 percent set from 1059 flowers bagged but not brushed and 1.9 percent from 799 flowers bagged and brushed. Hutson (43) obtained 4 percent on a Wealthy tree enclosed under a frame without bees with a Jonathan tree.

The data indicate that Wealthy is not sufficiently self-fruitful in the various localities. Moreover, the data, upon which the variety has been classified from self-unfruitful to self-fruitful, are probably not significantly different in view of the range of experimental error involved in pollination experiments.

Data given by Macoun in 1924 and 1925 (58, 59) do not agree with those which were given in 1923 (57). The percentage sets reported from selfed flowers are extraordinarily high. Chandler (11) stated that Wealthy seems to be self-fruitful to a satisfactory degree and that experience in the orchard with Wealthy agrees with the results of pollination studies. The objection to the acceptance of orchard observations as satisfactory evidence of the self-fruitfulness of this variety, as with Baldwin, lies in the fact that no results from careful surveys are available. Several other possible factors must be eliminated before the self-fruitfulness of Wealthy is considered established.

EFFECTIVENESS OF VARIETIES AS POLLINIZERS

The data at present available in the literature indicate that apple varieties fall roughly into two groups based upon their effectiveness as pollinizers The first group comprises those varieties which have shown themselves to be consistently effective pollinizers of other varieties. The second group comprises those which have not been consistently effective pollinizers. Few data have been presented in the literature as yet which will enable one to classify further the varieties in the first group upon the basis of their relative effectiveness as pollinizers for varieties in general.

BALDWIN

The evidence indicates that Baldwin has not been a consistently effective pollinating variety.

Baldwin appeared to be an effective pollinizer with Lewis and Vincent (52), who reported 56 fruits from 100 flowers of Esopus Spitzenburg pollinated by Baldwin; and with Morris (60), who reported 26 percent set from 26 flowers of Longfield and 38 percent from 26 flowers of McIntosh. Morris obtained no fruits from Jonathan pollinated by Baldwin.

On the other hand, Gowen (32) found the Baldwin to be of little value for Ben Davis, Golden Russet, Oldenburg, Red Astrachan, and Rhode Island Greening. Sax (67) showed that Baldwin was not a consistently effective pollinizer for Ben Davis, Russet, Northern Spy, McIntosh, and Rhode Island Greening. It was more effective on McIntosh than on the other varieties. Vinson (73) obtained no fruits from 260 flowers of Stayman Winesap pollinated by Baldwin. A Stayman Winesap tree enclosed under a muslin frame with a Baldwin tree with bees in the Bingham orchards

(Table 1) set 1.2 percent from 16,445 flowers, indicating that Baldwin is of little value as a pollinizer. Stout (69) in New York reported that Wealthy and Rhode Island Greening failed to set fruit when pollinated by Baldwin. Overholser (61) obtained no fruits from Baldwin as a pollinizer of Gravenstein.

It is thus evident that the Baldwin variety has not given consistent results, even as a pollinizer of varieties which usually give high percentages of set as female parents, as for example, Ben Davis, Oldenburg, and Wealthy. There is little justification to assume, however, that no fruits whatever will be produced when the variety is used as a pollinizer.

DELICIOUS

Delicious has been a consistently effective pollinating variety as indicated by considerable data (5, 60, 21, 33, 73, 2, 3, 61).

ENSEE

Ensee was introduced only recently. Limited data (45, 73) indicate that it is an effective pollinizer of Stayman Winesap.

GOLDEN DELICIOUS

Few data on the effectiveness of Golden Delicious as a pollinizer have yet been presented. Those of Lewis (53) indicate that the variety is a very effective pollinizer of Delicious, Grimes Golden, Jonathan, Rome Beauty, and Stayman Winesap.

GRIMES GOLDEN

Grimes Golden has been quite generally shown to be an effective pollinizer of other varieties (52, 71, 78, 61, 21, 2, 73). Recently Auchter and Schrader (4) reported unsatisfactory results from Grimes Golden pollen on Arkansas. However, Arkansas usually gives relatively low sets of fruit regardless of its pollinizer, indicating that a considerable proportion of its flowers are unable to set fruit. Grimes Golden has proved to be a very effective pollinizer for varieties which do not have this abnormality.

JONATHAN

Jonathan has been shown to be an effective pollinizer of other varieties by several investigators (52, 71, 78, 60, 21, 2, 33, 73, 4, 64, 61, 43).

McINTOSH

Data presented by several investigators (19, 54, 32, 60, 67, 2, 58, 59, 55) indicate that this variety is an effective pollinizer for other varieties.

NERO

Nero, in the few data presented, has not proved to be a consistently reliable pollinizer (14).

NORTHERN SPY

Several investigators (35, 32, 67, 45) have shown that Northern Spy is an effective pollinizer of other varieties.

OLDENBURG

The data presented by several investigators (5, 16, 21, 58, 59, 44) also indicate that Oldenburg falls in the group of effective pollinating varieties.

RHODE ISLAND GREENING

Rhode Island Greening, like Baldwin, has not proved to be a consistently effective pollinizer of other varieties. Morris (60) obtained no fruit when the pollen of Rhode Island Greening was placed on Fallawater and Jonathan. However, he reported 11 fruits from 25 flowers of Longfield and 3 from 47 flowers of Wagener pollinated by the variety. Sax (67) showed that Rhode Island Greening was not a reliable pollinizer for Ben Davis, Baldwin, and Northern Spy. Only "Russet" and McIntosh set an appreciable amount of fruit from its pollen. McDaniels (55) placed Rhode Island Greening flowers in tubs under a muslin frame enclosing a McIntosh tree and a hive of bees. The set from 15,822 flowers on the McIntosh tree was only 0.7 percent. Overholser (61) obtained no fruits from Rhode Island Greening pollen on 1239 flowers of Gravenstein and on 853 flowers of Tompkins King.

The data presented by these investigators do not justify the assumption that no fruits will be produced when Rhode Island Greening is used as a pollinizer. They do indicate, however, that it cannot be depended upon as an effective pollinating variety.

ROME BEAUTY

Rome Beauty has been shown by several investigators (71, 54, 1, 60, 2, 3, 45, 73, 53) to be a consistently effective pollinating variety, provided its blooming period overlaps that of the variety to be pollinated.

STAYMAN WINESAP

Data have been presented by several investigators indicating that Stayman Winesap is not an effective pollinating variety (14, 60, 2, 45, 53), altho the conclusion that no fruits whatever will develop when Stayman Winesap is used as the pollinizer is hardly

justified. As further support of this point Ballard (5) obtained 3.5 percent set from 225 flowers of Early Ripe and 4.6 percent from 878 flowers of Grimes Golden pollinated by Stayman Winesap; while Ingram, Nickajack, Rome Beauty, and Yellow Transparent set no fruits. Dorsey (21) obtained contradictory results. Stayman Winesap pollen on Fallawater, Hibernal, and Wealthy was not satisfactorily effective, but on Charlamoff, Okabena, Oldenburg and Patton Greening it gave high percentages of set. From data taken by Vinson (73), Table 1, with pairs of trees enclosed under muslin frames with bees, it is evident that Stayman Winesap was of little value as a pollinizer for Baldwin, Jonathan, and Yellow Bellflower.

TABLE 1.—Cross-Pollination of Stayman Winesap Trees Under Muslin Frames With Other Varieties, 1923

From Ohio Exp Sta Bul 373, 1924

No of pair	Varieties used	Number of flowers	Set of fruit	
			Number	Percent
1	Baldwin..	7,338	360	4.9
	Stayman Winesap	16,445	196	1.2
2	Jonathan	12,770	194	1.5
	Stayman Winesap.	5,515	335	6.0
3	Yellow Bellflower	3,065	5	0 2
	Stayman Winesap.	3,505	180	5.1

WEALTHY

Wealthy falls in the group of effective pollinating varieties as indicated by considerable data (54, 32, 60, 21, 2, 3, 58, 59, 43).

YELLOW TRANSPARENT

Data have been presented by several investigators (35, 5, 60, 73, 58, 59, 44) indicating that Yellow Transparent is an effective pollinizer of other varieties. Auchter (2, 3) reported that the variety is very effective in Maryland.

FRUITFULNESS OF VARIETIES AS FEMALE PARENTS

The writer has roughly classified apple varieties into two groups based upon their fruitfulness as female parents when pollinated by varieties which are generally known as effective pollinizers. The varieties placed in the first group are those which, following favorable weather conditions during the blooming and fruit-setting periods, pass thru the first drop (one to two weeks after petal fall) with several fruits remaining on a large proportion of their clusters. The varieties placed in the second group are

those which, under identical weather conditions, set a smaller average number of fruits to a cluster, usually one or two, than varieties in the first group.

Of the varieties used in this study, the writer places in the first group Baldwin, Ensee, Golden Delicious, Grimes Golden, Jonathan, Oldenburg, Rome Beauty, and Yellow Transparent. Open pollinated flowers of these varieties usually pass thru the first drop with three or four fruits remaining on a considerable number of clusters. They usually require heavy thinning. Data given in the pollination experiments of many investigators (14, 21, 71, 72, 54, 78, 32, 60, 21, 67, 33, 45, 58, 59) show that these varieties are very fruitful when pollinated by effective pollinating varieties.

The writer hesitates from the evidence available to classify definitely McIntosh and Northern Spy, altho it appears that they will fall into the first group.

The varieties of this study, included in the second group are Delicious, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap. Evidence from pollination and fruit-setting studies indicate that a considerable number of their flowers are incapable of setting fruit regardless of the pollinating variety (75, 63, 14, 5, 60, 21, 67, 45, 33, 3, 64). The data supporting this conclusion are in part the low percentages of set usually obtained when these varieties are pollinated by varieties with pollen of high germinability compared to the percentages obtained when the varieties in the first group are pollinated by the same varieties. These varieties may require light thinning and will usually produce satisfactory commercial yields of fruit. They occasionally fail to set satisfactory crops even following favorable external conditions and exhibit irregularities during the fruit-setting period.

Evidence supporting the classification of apple varieties into these groups was recently given by the writer (42).

EXPERIMENTAL PROCEDURE

SOURCE AND CULTURAL TREATMENT OF TREES

The trees used in the Wooster experiments were growing in the orchards of the Ohio Agricultural Experiment Station under a system of grass mulch, and were treated with sodium nitrate or ammonium sulfate. The soil is classified as Wooster silt loam. The age of the trees and the amount and form of nitrogen fertilizer applied each year are given in Table 2. The application of nitrogen was made one to three weeks before full bloom. The trees were

given a moderate pruning annually. All trees used in these experiments were strong and vigorous as indicated by length of terminal growth and size and color of the leaves. The yield of each tree in the year previous to pollination is also given in Table 2.

TABLE 2.—Age, Treatment, and Yield of Trees Used in Pollination Experiments, Wooster, 1924-1926

Variety	Tree	Date of planting	Fertilizer per tree	Year of pollination	Yield of tree in year	
					Previous to pollination	Of pollination
			Lb.		*Bu.*	*Bu.*
Baldwin	359	1912	5 sodium nitrate	1924	2.5	15.8
				1926	2.1	10.9
	395	1912	5 sodium nitrate	1926	0.0	26.0
Delicious	406—9	1900	5 sodium nitrate	1924	19.5	14.1
	406—7	1900	5 sodium nitrate	1925	5.8	18 8
	406—5	1900	5 sodium nitrate	1925	4.5	14.6
	279	1914	5 sodium nitrate	1926	19.8	24.8
Ensee	411—1	1904	5 sodium nitrate	1924	1.3	12.7
				1925	12.7	2.5
	411—2	1904	5 sodium nitrate	1924	4.2	2.6
				1925	2.6	8.2
	411—3	1904	5 sodium nitrate	1924	1.8	5.7
				1925	5.7	7.3
Golden Delicious	396	1920	1½ am. sulfate	1926	0.7	0.1
	411—1	1922	1½ am. sulfate	1926	0.2	0.7
	411—2	1921	1½ am. sulfate	1926	0.2	0.2
	411—3	1921	1½ am. sulfate	1926	0 2	0.8
	411—4	1921	1½ am. sulfate	1926	0.2	0.9
	411—5	1921	1½ am. sulfate	1926	0.3	0.9
Grimes Golden	410—7	1900	3 4/5 am. sulfate	1924	4.0	36.2
				1926	6.1	39.2
	410—9	1900	5 sodium nitrate	1925	6.7	16.8
Jonathan	408—7	1900	3 4/5 am. sulfate	1924	12.2	10.0
	408—8	1900	3 4/5 am. sulfate	1925	3.3	16.2
Nero	362	1904*	5 sodium nitrate	1925	8.1	4.3
Northern Spy	167	1893	5 sodium nitrate	1924	8.4	16.2
				1925	16.2	4.5
	169	1893	5 sodium nitrate	1924	36.0	27.0
Ohio Nonpareil	183	1913	5 sodium nitrate	1925	9.9	2.1
				1926	2.1	9.0
Oldenburg	132	1893	5 sodium nitrate	1926	0.1	30.8
	383	1905	5 sodium nitrate	1926	0.1	13.3
Rhode Island Greening	229	1893	5 sodium nitrate	1925	9.0	37.5
	227	1893	5 sodium nitrate	1926	46.0	17.8
Rome Beauty	430	1905	5 sodium nitrate	1924	6.9	4.5
				1925	4.5	9.7
				1926	9.7	18.9
Stayman Winesap	374	1900	5 sodium nitrate	1924	7.2	6.6
				1925	6.6	13.5
	8—3	1916	¾ am. sulfate + 1 sodium nitrate	1925	.....	.....
	E—4	1916	7 sodium nitrate	1925	0.5	3.2
Wealthy	463	1905	5 sodium nitrate	1924	0.2	8.8
				1926	1.0	10.0
	290	1893	5 sodium nitrate	1926	5.1	8.1
	291	1893	5 sodium nitrate	1926	5.1	9.6
Yellow Transparent	84	1893	5 sodium nitrate	1926	0.4	29.2

*Top grafted.

The trees used in the experiments at Hamden, Geauga County, Ohio, were planted in the spring of 1915. They were growing under a system of tillage with a soybean cover crop and with yearly fertilization with 1½ pounds of ammonium sulfate to a tree. The soil is classed as Volusia silt loam, a type which is low in organic matter. The addition of ammonium sulfate to the tilled trees slightly darkened the color of the foliage. The trees were strong and vigorous but gave no indications of being in an excessively vegetative condition. They received a light pruning annually and were well cared for at all times (Fig. 1).

WEATHER CONDITIONS DURING BLOOMING SEASONS

The duration of the hand-pollination work at Wooster in 1924 was from May 7 to 17. The period of full bloom, depending upon the variety, ranged from May 8 to 18. The maximum and minimum temperature and amount of rainfall during May for Station 1, located at the Administration buildings, one mile from the orchard, are given in Table 3. The general notes for the days during which the hand pollinations were made, were taken in the orchards.

TABLE 3.—Weather Record at Station 1, One Mile From Orchard, Wooster, 1924

Date	Temperature		Rainfall inches	Notes
	Max.	Min.		
May 1	56	36	.02	Cloudy ¾ day
2	68	41	.....	Clear
3	66	44	.27	Cloudy
4	61	36	T	Clear
5	69	35	.....	Clear
6	85	50	....	Clear
7	84	50	.....	Clear, humidity high
8	83	56	T	Clear ¾ day, cool
9	65	48	.12	Cloudy, cool
10	62	37	T	Cloudy, cool, humidity high
11	58	43	.54	Cloudy, cool, humidity high
12	53	46	.28	Cloudy, cool, humidity high
13	67	37	.01	Cloudy, cool, humidity high
14	64	47	.93	Cloudy
15	58	41	.54	Cloudy, cold
16	65	44	.02	Clear ½ day, cool
17	72	45	.....	Clear ½ day, windy, humidity high
18	69	54	.47	Cloudy ¾ day
19	57	36	T	Cloudy
20	57	41	.....	Cloudy
21	62	35	T	Cloudy
22	63	32	T	Cloudy
23	72	40	T	Cloudy
24	67	47	.42	Cloudy
25	58	37	.02	Cloudy
26	66	35	.01	Clear
27	63	50	.05	Cloudy
28	71	53	.08	Cloudy
29	70	50	.33	Cloudy
30	60	39	.02	Clear
31	69	34	.....	Clear ¾ day

T=trace.

Fig. 1.—Grimes Golden tree used in pollination experiments at Hamden in 1925

This tree is typical of the size of trees used in the Hamden experiments, 1924-1926

Altho the weather during the greater part of the blooming season was rather unfavorable for insect pollination, with occasional periods of sunshine and favorable temperature, the set of fruit thruout the orchards was excellent.

The period of pollination work at Hamden in 1924 extended from May 26 to 31. No detailed temperature records were taken in the Hamden orchards, but the general weather observations during the period are given in Table 4. The conditions were more favorable for insect visitation than at Wooster. The set of fruit in percentage of bloom was, in general, quite satisfactory.

TABLE 4.—Notes on Weather Conditions, Hamden, 1924

Date	Notes
May 26	Clear, cool
27	Dull, cloudy, cool all day, slight rain in forenoon
28	Misty during forenoon, clear, hot during afternoon
29	Cool during day, trace of rain, cloudy
30	Cool during forenoon, clear, warm during afternoon
31	Clear, warm

In 1925, Station 2 was established in the orchards at Wooster, within a few hundred yards of all trees used in the experiments. The weather data for the period from April 15 to May 15 are given in Table 5. In 1925 the temperature became very high on April 22 and brought the flowers of all varieties into full bloom from April 24 to 28. The hand pollinations were made during the period from April 23 to 28. The weather was ideal for insect visitation until April 28 when a cold period began. As indicated in Table 5, light frosts occurred on May 2, 7, and 12, but no injury was evident in the setting fruits. A heavy frost during the night of May 24-25 did considerable damage to the developing fruits, which were ½ to ¾ inch in diameter.

At Hamden, in 1925, the pollination work was done on May 8 to 10. At the time of the heavy frost during the night of May 24-25, the petals had just fallen from the flowers. Due to the fact that the temperature dropped quite low in parts of the orchard the flowers from only a few trees of those used in the pollination experiments escaped injury.

In 1926 the pollination work at Wooster extended from May 10 to 19. The flowers of all varieties used reached full bloom during the same period. As indicated by the data in Table 6, the weather conditions during the pollination season were very favorable for insect visitation, pollen germination, and pollen-tube growth. The set of fruit was excellent thruout the orchards.

TABLE 5.—Weather Record at Orchard, Wooster, 1925

Date	Temperature		Rainfall inches	Notes
	Max.	Min.		
April 15	54	43	.47	Clear ¾ day
16	54	32	T	Clear
17	57†	36†	T	Cloudy ¾ day
18	64	37	.01	Clear ½ day
19	56	41	T	Cloudy
20	55	34	.....	Clear ½ day
21	61	33	. . .	Cloudy ¾ day
22	77	48	.. . . ..	Cloudy
23	88	58	.....	Clear
24	90	63	.....	Clear
25	86	66	T	Clear ¾ day
26	81†	52†	.12	Clear
27	68†	45†	. .... .	Clear ¾ day
28	58	46	.....	Clear ¾ day
29	57	37	.08	Cloudy
30	47	32	.36	Cloudy
May 1	54	38	.03	Cloudy
2	57	30	.....	Clear ¾ day, light frost
3	61	34	.02	Cloudy ¾ day
4	59	41	.48	Cloudy
5	48	36	.06	Cloudy
6	55	35	.12	Cloudy
7	55	30	.02	Cloudy, light frost
8	64	34	.....	Cloudy
9	67	41	.....	Clear
10	65	41	.73	Cloudy
11	61	41	T	Clear
12	66	30	.....	Clear, light frost
13	73	37	... .	Clear
14	70	46	.....	Clear
15	67	35	.....	Clear

T=trace. †Temperature at weather station 1 mile from orchard.

TABLE 6.—Weather Record at Orchard, Wooster, 1926

Date	Temperature		Rainfall inches	Notes
	Max.	Min.		
May 1	83	41	.21	Clear ¾ day
2	83	58	T	Clear
3	83	46	.38	Clear
4	54	30	.....	Clear
5	69	36	. ...	Clear
6	81	48	.... . .	Clear
7	86	52	.. ....	Clear
8	83	50	. ...	Clear
9	80	46	.. ..	Clear
10	62	36	T	Cloudy
11	61	33	.. ..	Clear, cold wind
12	65	37	.....	Clear
13	68	31	.02	Cloudy
14	68	40	.10	Cloudy
15	62	44	.34	Clear ½ day
16	76	37	.....	Clear
17	79	52	.11	Clear ½ day
18	80	54	.16	Clear ½ day
19	67	52	.37	Cloudy
20	66	41	T	Clear
21	78	44	.....	Clear
22	74	56	.25	Cloudy
23	57	41	.01	Cloudy
24	72	44	.....	Clear
25	70	42	T	Clear ¾ day
26	66	48	.07	Cloudy
27	71	43	.05	Clear
28	75	43	.....	Clear
29	82	47	. .....	Clear
30	84	51	.31	Clear ½ day
31	81	47	.25	Clear ½ day

T=trace.

The pollination work at Hamden in 1926 was done on May 21 and 22, the trees reaching full bloom May 25 to 27. General notes of the weather conditions from May 20 to 30 are given in Table 7. The set of fruit on all varieties except Stayman Winesap was fairly satisfactory.

TABLE 7.—Notes on Weather Conditions, Hamden, 1926

May 20	Clear, bright; temperature 40—60° F, warming to 60°.
21	Clear, bright, strong winds, temperature 40—60°.
22	Misty, cloudy forenoon, light showers afternoon; temperature 50°.
24	Clear, bright; temperature 45—60°.
25	Clear, bright, cold winds; temperature 45—60°.
26	Cloudy all day, cool.
27	Clear, bright, moderate, warm.
28	Clear, bright; temperature 50—60°.
29	Clear, bright; temperature 50—65°.
30	Cloudy, thundershowers and wind during afternoon, removing majority of petals; temperature 70—80°.

VIGOR OF TREES AND FLOWERS SELECTED

Due precautions were taken in the selection of strong and vigorous trees that were free from diseases and insect pests, and in the selection of vigorous flowers on each tree. It has been shown by several investigators (6, 7, 49, 50, 51, 39, 37, 22) that a large proportion of the flowers fall at the first drop, one to two weeks after petal fall, from trees which are low in vigor and whose growth is limited by a deficiency of available nitrogen. Since these flowers fail to develop regardless of the effectiveness of the pollinating variety, they must not be pollinated if reliable results are to be obtained.

It has been stated that trees in their *light-bearing year* and trees in an *overvegetative condition* should not be used in pollination investigations. Because of the relation of these statements to the trees used in these experiments and because of the importance of careful interpretation of the literature on this phase of the pollination problem, the evidence has been considered in detail.

Trees in Light-bearing Year

Macoun (59) in support of his contention that trees which are in their light-bearing year, following a year of heavy fruiting, should not be used in pollination experiments, presented limited data showing that a considerably smaller percentage set was obtained from the same pollen varieties on a McIntosh tree in 1924 than was obtained in 1923. No data were given as to the possible differences in percentage set of the open-pollinated flowers on the

tree in the two years, or as to the age and vigor of the tree in the spring of 1924. The justification for assuming that differences in the percentage set on a tree from flowers pollinated two years by the same variety are due necessarily to the inadequate nutrition of the flowers on the trees during the light-bearing year has not been established. Other factors, such as low temperature during the blooming season and pollen viability, may occasionally be of considerable importance.

Unquestionably, conditions can be postulated under which a tree that bore a heavy crop of fruit one year would not give as high a percentage set the subsequent year. For example, Hendrickson (38) presented data indicating that exceedingly heavy yields of French Prune (tree enclosed under frame with bees) weakened the tree so that the percentage set of flowers the following year was considerably decreased. Moreover, drought during the main-bearing year might also weaken a tree to such an extent that, despite heavy fertilization and sufficient moisture during the following spring, a larger percentage of the flowers formed would fall without setting fruit than in the year of heavy flowering. The writer has obtained evidence that trees of annual bearing varieties, as Rome Beauty, may be kept sufficiently vigorous by fertilization and pruning, provided sufficient moisture were present, to sustain as high percentage of set one year as another. However, little evidence is available to indicate whether vigorous trees which tend to produce heavy crops one year and light crops the following year under good cultural conditions have a lower percentage set of fruit the light-bearing year than during the heavy-bearing year.

It is undoubtedly true, however, that regardless of the factors involved, negative results obtained from a tree used as the female parent during its light-bearing year following a year of heavy fruiting must be carefully interpreted. The normal set of open pollinated flowers on such a tree is an invaluable aid in determining the confidence one should place in his interpretations.

Trees in an Overvegetative Condition

Kraus (47), Macoun (59), and others have stated that trees in an overvegetative condition should not be used in pollination experiments. It has been assumed by some that young trees during the few years previous to the formation of their first flowers and during the first years of flowering are overvegetative. In consequence of this condition it is contended that the tree will tend to drop its flowers without setting fruit regardless of the pollinating

variety. In this connection, also, Chandler (11) has stated that young trees making a very vigorous growth and which have not yet begun to bear profitable crops, are more liable to lose their flowers without setting fruit. He interpreted Powell's work (62) to indicate that pollination is less successful in Delaware with young apple trees than with older ones. Despite the possible truth of the general statement in regard to pollination in Delaware, it is questionable whether Powell's work should be so interpreted. Powell pollinated Stayman Winesap with York Imperial and Missouri Pippin, York Imperial with Missouri Pippin, and Missouri Pippin with York Imperial. He stated that the flowers of Stayman Winesap, York Imperial, and Missouri Pippin developed to the size of "peas" and then fell along with the open-pollinated fruits. The abscission, therefore, was concerned not with flowers which lacked pollination but with very young fruits in which, in all probability, fertilization had occurred (20).

Gardner, Bradford, and Hooker (29) stated that vigorous trees just coming into bearing have been observed to be more likely to drop their "fruit" than somewhat older trees of the same varieties. It seems to the writer that a distinction must be made between the abscission of flowers which may not have been fertilized and those developing young fruits which have passed thru the first drop. As Chandler (11) has stated, under practical orchard conditions there is little or no evidence that fertilized, developing young fruits, can be made to abscise by excessive vigor, such as can be initiated by heavy fertilization.

That the abnormal abscission of flowers does occur with certain varieties during the first years of flowering when the conditions are favorable for cross pollination and an abundance of bees are present, is not denied. Data from these varieties may be of little or no value in determining the degree of self-fruitfulness of the varieties or their effective pollinizers. However, there is no justification from the available evidence, either from observations in the orchard or from fruit-setting experiments, to warrant the conclusion that the young trees of *all* varieties in their first years of flowering tend to drop their flowers without setting fruit. Young trees of Baldwin, Wealthy, and Oldenburg during the first years of flowering, for example, tend to retain as many as three and four fruits to a cluster after the first drop. If abnormal abscission in certain varieties is to be ascribed to the overvegetative condition of the trees, two conclusions in regard to overvegetativeness in apple trees are possible.

Either the overvegetative condition results in a different response in one variety than in another or young trees of some apple varieties are not overvegetative.

Delicious is a variety which tends to drop its flowers without setting fruit while trees are young. Trees 2, 5, 49, and 60 (Table 14), of this variety, at Hamden, in 1924, altho having a moderate bloom, failed to develop fruits. These trees had been bearing flowers for two or three years but had never produced a satisfactory crop. They appeared to be of normal vigor for the variety and gave no evidence of overvegetative growth. The Baldwin trees of the same age which bloomed in this orchard set satisfactory crops of fruit.

Position of Flower Clusters

Fletcher (27) stated that flowers on terminals are not likely to set as well as those on strong lateral shoots. The writer observed no smaller set from the flowers on long terminals than from those on strong lateral shoots and vigorous spurs. The position of the flowers depends in large part upon the bearing habits of the variety. As the bearing habits of Grimes Golden and Baldwin, for instance, become established, flowers are borne on spurs as well as on terminals.

NUMBER AND POSITION OF FLOWERS POLLINATED

The percentage set of flowers is often higher in those clusters reduced to one or two flowers at the time of pollination than in those in which all flowers of a cluster are pollinated. The elimination of flowers decreases the competition for food and water which probably exists between the fertilized flowers, and which might prevent a number from surviving the first drop.

In the pollination work reported in this bulletin, unless otherwise stated, the clusters were thinned to two large unopened lateral flowers. Central (terminal) flowers of clusters were pollinated on one tree only (Table 15).

COLLECTION OF POLLEN

In this study large central or lateral flowers, which under favorable conditions were within a day or two of opening and exposing the anthers, were taken from the tree. The petals were taken off and the anthers and filaments removed by pulling the flowers over the blunt edge of a labeled petri dish. Whenever weather conditions permitted, the anthers and pollen were thoroly

dried by exposing them to the direct rays of the sun. In cool, cloudy, rainy weather they were dried in the laboratory in the petri dishes with the covers partially removed. The dried and shriveled anthers and filaments were allowed to remain in the dishes with the pollen.

STORAGE OF POLLEN

The method suggested by Keil (45), with slight modification, was found to be very satisfactory. The dry pollen and anthers were poured into No. 000 gelatin capsules. If the pollen were thoroly dry, it adhered to the entire inner surface of the capsule as a thick, yellow dust. A small piece of cardboard giving the variety of pollen was dropped into each capsule and the capsule placed in a tin compartment in the carrying case. The cover of the compartment was labeled with the variety of pollen and its date of collection. The capsules of each variety were kept separate. The pollen was used not later than one week after removal from the tree.

Fig. 2.—Stage of central flower at time of emasculation and pollination of lateral flowers

Variety—Stayman Winesap

Each pollination worker washed his hands in alcohol on changing from one variety of pollen to another. Extreme care was used to prevent contamination of pollen.

RELATION OF EMASCULATION TO TIME OF POLLINATION

The flowers were pollinated immediately after emasculation. The lateral flowers of a cluster were never emasculated and pollinated until the central flower had opened sufficiently to expose the anthers (Fig. 2). These lateral flowers at this stage were, under favorable weather conditions, within two days from opening and exposing the pistils. No flower was emasculated and pollinated which had the petals unfolded sufficiently to expose the anthers or pistils.

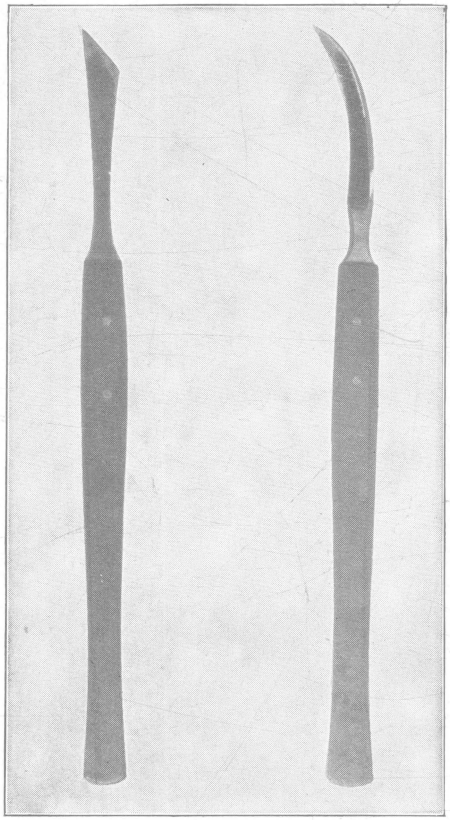

Fig. 3.—Types of scalpels found most satisfactory for emasculation of apple flowers

EMASCULATION OF FLOWERS

Thruout the work, the writer had the assistance of competent high school and college students. Small dissecting scalpels (Fig. 3) were used. In 1924 and 1925 the petals, stamens, and tips of the calyx lobes only were removed. At that time it was felt that the danger of injury to the pistils was too great if the cuts were made below the calyx lobes. In 1926 several of the most careful and experienced men made the cut below the calyx lobes. The calyx lobes, corolla and stamens were removed following one or two cuts (Fig. 4). From previous observation it appeared that as satisfactory a set would be obtained from flowers in which the upper part of the receptacle was removed as from those in which only the tips of the calyx lobes, petals, and anthers were removed.

METHOD OF SELF-POLLINATION

The selfed flowers were emasculated and pollinated regardless of whether they were bagged or not. In pollinating flowers the top of the gelatin capsule was removed and placed over the pistil of the emasculated flower. A slight turning of the top while touching the stigma removed a large number of pollen grains and profusely pollinated the flower. Each capsule was discarded as soon as the inside ceased to show the covering of pollen.

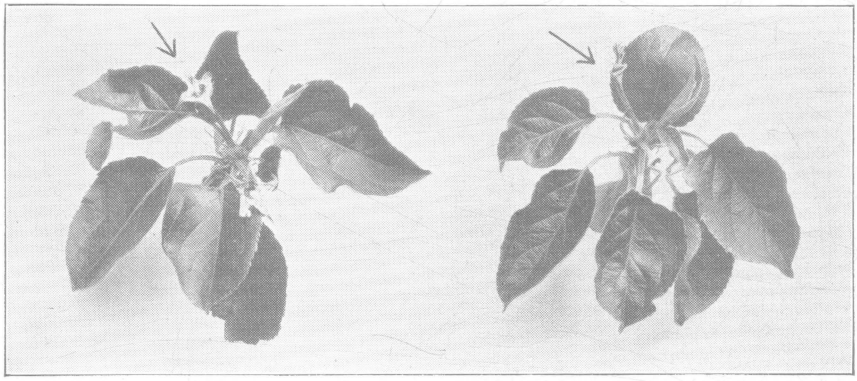

Fig. 4.—Two types of flower emasculation

Left—Petals, stamens, and tips of calyx lobes only removed
Right—Petals, stamens, and calyx lobes removed

GERMINATION OF POLLEN

Germination tests were made of all pollen used on each of the trees in these experiments. The media used in 1924 and 1925 was 10-percent cane sugar—2-percent agar-sterile yeast (10). In 1926 the sterile yeast was omitted from a number of plates with no difference in results. The temperatures for the germination tests were 28° C. in 1924 and 1925 and 15°, 20° and 25° in 1926.

METHODS OF INSECT EXCLUSION

In 1924 and 1925 1-pound white transparent "glassine" paper bags were placed over the two pollinated flowers of a cluster (Fig. 5). It was thought unwise to include more than this number, due to the possibility of injury to the flowers. The bags were torn open one to two weeks after petal fall to allow for growth of the secondary shoots from the cluster bases and to enable the full amount of light to reach the growing leaves and fruits. In 1926 the method

used by Sax (67) was also employed. A considerable number of the flowers used in both the selfing and cross-pollination experiments were left exposed after emasculation and pollination.

TABULATION OF RESULTS

The count of fruits resulting from the hand self-pollinations was taken between the first drop and the beginning of the June drop in open pollinated fruits. A later count would have been made had any appreciable number of selfed flowers survived the first drop. The fruits on the Baldwin tree enclosed under muslin frame were counted after the first drop and at two other times during the summer until the fruits ceased to abscise.

Fig. 5.—"Glassine" bags enclosing pollinated flowers

In the cross-pollination experiments the fruits set were counted just before the beginning of the June drop. This time was at least four or five weeks after the date of pollination or approximately three weeks after petal fall. No second count was made after the June drop.

The normal set of open pollinated flowers was usually taken before the June drop, at the same time as the hand pollinations. In 1925 the normal set of open-pollinated flowers was taken after the

first drop and before a second drop which consisted of partially developed frost-injured fruits (40). In several varieties in 1926 the normal set was taken to include only the fruits which were going to survive the June drop.

The writer is of the opinion, for reasons given elsewhere (41), that, where three or more flowers on a cluster are pollinated, the most valuable count of fruits set is one taken before the second or "June" drop. Later counts may be made, if so desired, but the results obtained therefrom must be carefully interpreted, as far as the relative effectiveness of varieties which are good pollinizers is concerned.

In reducing the number of flowers of a cluster pollinated to two, the percentage set of flowers after the first drop was unquestionably increased over the probable set if all flowers of the cluster had been pollinated. That this reduction of flowers eliminated the greater part of the competition for food and water between the pollinated flowers is probable.

MODE OF EXPRESSION OF RESULTS

Pollination results have usually been expressed in terms of the percentage of pollinated flowers that set fruits. This has been compared with the percentage of open-pollinated flowers that developed into fruits. Results from self and cross pollinations in which little or no fruit was obtained have, however, occasionally been published with no mention of the normal set of open-pollinated flowers on the same tree. In such cases one is called upon to assume that the investigator did not present negative results from the hand pollinations, if the open-pollinated flowers on the same tree also set no fruits. Were some of these data not supported by later work in which the normal set of open pollinations was given, they would be discredited.

Some discussion has arisen recently as to the best manner of expressing the results of self- and cross-pollinated flowers as well as the normal set of open-pollinated flowers. McDaniels (56) suggested that they be expressed as follows: (1) total number of spurs on branch used, (2) number with flowers, (3) number of spurs pollinated, (4) number of spurs holding fruit. He stated that the data on a spur rather than a flower basis would give the relation of the pollination results to a full crop on the tree. It is true that, with data on the flower basis, the relationship of the pollination results to a commercial yield is not readily apparent. Altho it has been stated that a 3- to 7-percent set of the flowers on a tree indicates

that a full crop is present, it is obvious that the number of flowering points is an important factor in determining whether a certain percentage set indicates a full commercial crop.

However, before the relation of data, on a spur basis, to a satisfactory commercial crop can be appreciated, an arbitrary definition of such a crop in terms of the proportion of growing points (both flowering and non-flowering) which must hold at least a single fruit, must be agreed upon. Moreover, the calculation of data to the spur basis also assumes that all spurs which hold flowers on a particular branch are of equal vigor to those spurs whose flowers are pollinated. Obviously, since only the strong spurs are pollinated, the data obtained should not be considered as representative of all spurs. With data on the flower basis the average fruits per spur can be determined, when the number of flowers pollinated to a spur is known. With additional data as to the percentage of growing points which bore flowers on a given branch, the flower basis for the expression of data should be as satisfactory, from a practical point of view, as data on the spur basis.

PRESENTATION OF THE DATA

All data obtained from each tree, with one or two exceptions, are presented separately. The number of flowers pollinated in many cases was small. However, in view of the excellent vigor of spurs and terminals chosen and the extreme care used in all details of the work, it is felt that the data are representative of the results to be expected from the use of a large number of flowers.

BALDWIN

RESULTS FROM HAND-POLLINATED SELFED FLOWERS

At Wooster in 1924 on tree 359 (Table 8) no fruits were obtained from selfed flowers. Grimes Golden, Jonathan, and Wealthy were effective pollinizers. Stayman Winesap pollen gave no fruits. In 1926 Baldwin flowers selfed and bagged produced no fruits, while the uncovered flowers gave 2.6 percent set. Banks, Ohio Nonpareil, and Rhode Island Greening were not sufficiently effective pollinizers. Delicious, Ensee, and Jonathan were effective pollinizers. Grimes Golden gave a somewhat lower set than the other varieties but indicated its value as a pollinating variety. Except with Delicious, the differences between the percentages set of the bagged and open flowers do not appear to be significant.

TABLE 8.—Pollination of Baldwin, Wooster

Pollen variety	Exposure of flowers	Number of flowers pollinated	Percentage set
Tree 359, pollinated May 15, 1924			
Baldwin*	Bagged	92	0
Grimes Golden	Bagged	94	57.4
Jonathan	Bagged	86	51.2
Stayman Winesap*	Bagged	64	0
Wealthy	Bagged	96	57.3
Open set			
Entire cluster		110	42.7
Tree 359, pollinated May 15, 1926			
Baldwin*	Bagged	164	0
	Open	152	2.6
Banks*	Bagged	58	0
	Open	34	8.8
Delicious	Bagged	714	63.5
	Open	80	40.0
Ensee	Bagged	48	81.2
	Open	52	82.7
Grimes Golden	Bagged	14	14.3
	Open	86	9.3
Jonathan	Bagged	36	66.7
	Open	92	55.4†
Ohio Nonpareil*	Bagged	58	0
	Open	48	0
Rhode Island Greening*	Bagged	70	2.9
	Open	178	2.8†
Open set			
Entire cluster		733	35.2

*Pollen of very low germinability.
†Jonathan had 2 fruits and Rhode Island Greening 1 fruit, not included, which were small, yellowing, enlarged over petal-fall stage, but falling.

At Hamden in 1924 (Table 9) Baldwin flowers selfed produced no fruits. Delicious, Grimes Golden, Jonathan (to a lesser degree), McIntosh, and Yellow Transparent proved valuable pollinizers. In 1925 selfed flowers again produced no fruits. Jonathan gave a satisfactory set, while Nero was an ineffective pollinizer. In 1926, selfed flowers, either bagged or left open, produced no fruits. Delicious gave high percentages set from both the bagged and open flowers. Rhode Island Greening proved to be an ineffective pollinizer. The bagged flowers of Jonathan gave a high percentage set, while the open flowers failed to develop into fruits. It is possible that this was due to drying of the pistils following emasculation. The open-pollinated fruits that would remain after the June drop were easily recognizable on June 23, when the count of fruits was taken.

All data obtained from the hand-pollinated flowers, whether bagged or left uncovered, indicate that Baldwin is not self-fruitful to a sufficient degree to give a satisfactory commercial crop. Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap

were of little value as pollinizers of Baldwin, apparently in consequence of the very low germination of their pollen. Delicious, Grimes Golden, Jonathan, McIntosh, and Yellow Transparent had pollen of high germinability and were effective pollinating varieties. Moreover, the percentage sets of the flowers bagged and left uncovered following emasculation and self-pollination, with two exceptions, were probably not significantly different.

TABLE 9.—Pollination of Baldwin, Hamden

Tree No.	Pollen variety	Exposure of flowers	Number of flowers pollinated	Percentage set
	Trees pollinated May 28, 29(†), June 2(‡), 1924			
9	Baldwin*	Bagged	90	0
	Grimes Golden	Bagged	198	65.7
	Jonathan	Bagged	18	16.6
	McIntosh	Bagged	210	31.9
	Open set			
	2 flowers		200	42.0
	Entire cluster		100	29.0
6	Delicious	Bagged	102	44.1
	Open set			
	Entire cluster		157	26.1
	Central flower only		17	82.4
7	Jonathan†	Bagged†	166	7.2
11	Baldwin*	Bagged	34	0
	Open set			Satisfactory
12	Baldwin*	Bagged	32	0
	Open set			Satisfactory
29	Baldwin*	Bagged	34	0
	Open set			Satisfactory
46	Yellow Transparent‡	Bagged	92	41.3
	Open set			Satisfactory
	Trees pollinated May 8, 1925			
1	Baldwin*	Bagged	72	0
	Jonathan	Bagged	22	22.7
	Open set			
	Entire cluster		533	7.3
2	Nero*	Bagged	66	0
	Open set			Satisfactory
3	Baldwin*	Bagged	58	0
	Open set			Satisfactory
	Trees pollinated May 21 or 22†, 1926			
1	Baldwin*	Bagged	146	0
		Open	160	0
	Delicious	Bagged	120	76.7
		Open	202	67.8
	Open set**			
	Entire cluster		532	16.3
2	Rhode Island Greening*†	Bagged	74	1.5
		Open	32	0
	Jonathan†	Bagged	74	50
		Open	30	0
	Open set**			
	Entire cluster		213	16.9

*Pollen of very low germinability.
**After June drop.

RESULTS WITH TREE UNDER MUSLIN FRAME

At Wooster in 1926 tree 395 was enclosed under a frame with a hive of bees (Fig. 6). The material used was the thinnest grade of muslin capable of withstanding the strain of wind storms. Ordinary mosquito netting was not used because of the possibility of its allowing the entrance of small insects. The bees were placed under the frame early on the morning of May 7, before any flowers had opened in the vicinity. The high temperature that day commenced to open the central flowers of Ohio Nonpareil and Oldenburg, the earliest blooming varieties in the orchards. The Baldwin tree reached full bloom on May 16. The weather conditions during the blooming of the central and lateral flowers (Table 6) were exceptionally favorable. During the entire period of full bloom the bees repeatedly visited the flowers.

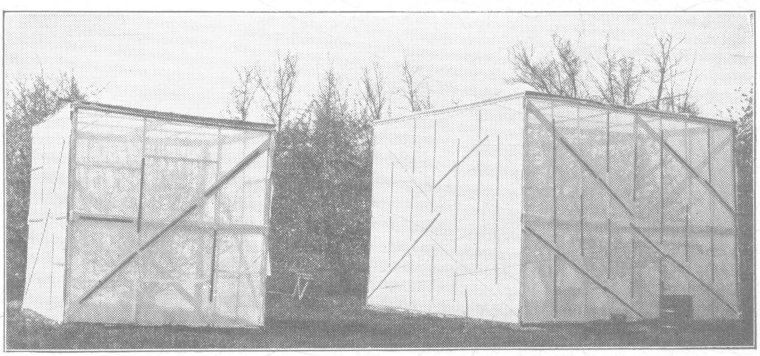

Fig. 6.—Trees enclosed under frames with bees, May 1926

Left—Golden Delicious tree 396 with Baldwin flowers in pails and bees enclosed
Right—Baldwin tree 395 enclosed with bees

All flowers on one-half of the tree were counted and the number doubled, for the entire tree. The first count of fruits set was made on June 12, shortly before a second drop started on the tree. On June 30, just after the second or June drop in the orchard was complete, all fruits on the tree were recounted. Early in July a third drop of partially developed fruits was observed. On July 15 the abscised fruits and those about to fall were counted. All fruits were again counted at harvest time.

The data for this tree are given in Table 10. From 21,226 flowers 1588 fruits (7.4 percent) had set on June 12. In addition 214 fruits that had only slightly enlarged over the petal-fall stage

were counted. These were seedless, yellow, wilted, and easily snapped off when their pedicels were bent. From June 12 to June 30, 174 fruits abscised, reducing the set to 6.7 percent. From June 30 to July 15, 130 fruits abscised, reducing the set still further to 6 percent. At harvest time 1281 fruits were counted, giving a total yield of 471 pounds (10.9 bushels).

TABLE 10.—Pollination of Baldwin, Wooster, 1926

Tree 395, enclosed under muslin frame with bees

Number of flowers on tree	21,226
Number of fruits set June 12	1,588
Number of enlarged receptacles removed on June 12	214
Percentage set June 12	7.4
Number of fruits set June 30	1,414
Percentage set June 30	6.7
Number of fruits set July 15	1,284
Percentage set July 15	6.0
Number of fruits at harvest, October 22	1,281
Percentage set October 22	6.0
Yield of tree October 22, pounds	471
Yield of tree October 22, bushels	10.9
Average weight of single fruit, pound	0.37
Average number of fruits per bushel	117

The relation of the amount of fruit on this tree to a full commercial crop is indicated in part by a comparison of the data given in Table 10 with that given in Table 11 for tree 359, exposed to open pollination by insects.

TABLE 11.—Set of Fruit on Baldwin Tree 359 Exposed to Cross Pollination by Insects, 1926

Percentage set before June drop June 9	25.2
Percentage set after June drop June 30	19 7
Percentage set after thinning July 15	11.0
Yield of tree at harvest, bushels	26.0
Average weight of single fruit, pound	0.31
Average number of fruits per bushel	146

The two trees, 359 and 395, are of the same age and had received the same cultural treatment (Table 2). The open-pollinated tree 359 was somewhat larger. Both had an abundant bloom. The tree exposed to open pollination held a full crop of fruit, while the tree enclosed under the frame, produced a fairly satisfactory commercial yield (Fig. 7). This resulted in part from the fact that many of the fruits on 395 were considerably larger than those on tree 359 (Tables 10 and 11). This was unquestionably due to the abscission of such a large percentage of the flowers (92.6 percent) at the first drop, thus making available a greater supply of food and water to the fruits remaining.

Fig. 7.—Sections of self- and cross-pollinated Baldwin trees
Left—Tree 395 selfed by enclosing under frame with bees
Right—Tree 359 open pollinated
Note very vigorous terminal shoots and large leaves on selfed tree.

The average seed content of the fruits falling at the various stages of development from each tree is given in Table 12. The undeveloped seed coats, which were not counted as "seeds", were less than one-third the size of a pin head.

TABLE 12.—Seed Content of Baldwin Apples

Tree 395 enclosed under muslin frame and Tree 359 exposed to open pollination, Wooster 1926

Tree No.	Date of collection	Total number of fruits collected	Average seed content per apple	Number of fruits with number of seeds as follows										
				0	1	2	3	4	5	6	7	8	9	10
395	June 30	91	0.78	31	49	11	0	0	0	0	0	0	0	0
359	June 30.....	104	5.13	0	0	3	6	26	32	18	14	5	0	0
395	July 15.....	130	0.97	22	91	16	1	...	..	..	..	..	..	...
395	Oct. 22. ...	771	1.77	24	327	269	108	29	12	2	0	0	0	0
359	Oct. 22.....	172	5.78	0	5	2	11	20	31	43	32	19	7	2

The partially developed fruits falling from the selfed tree on June 30 had a much lower average seed content per apple than the open-pollinated fruits abscising on tree 359. From tree 395, 34 percent of the fruits falling prior to June 30, 17 percent of those abscising from June 30 to July 15, and 3.1 percent of those remaining at maturity had no seeds (Fig. 8). The average seed content of the mature fruits on the open-pollinated tree was considerably higher than that of the mature fruits on the selfed tree.

A larger percentage set was obtained from the selfed flowers on the tree enclosed under the frame with bees than from the hand-pollinated flowers on tree 359 (Table 8) or from any of the selfed hand-pollinated flowers. It thus appears that the two methods commonly used to determine the degree of self-fruitfulness of a variety did not give similar results. Altho the differences in set obtained from the two methods did not amount to more than 4 percent, yet such a variation represented a considerable number of fruits.

DELICIOUS

Selfed flowers on Delicious tree 406-9 at Wooster in 1924 set 2.6 percent (Table 13). The data obtained from Golden Delicious and Grimes Golden as pollinating varieties were characteristic of the results usually obtained from emasculated flowers of Delicious regardless of whether the flowers were bagged or left uncovered. Stayman Winesap produced no fruits. The first drop from the tree was exceedingly heavy and only a fair set developed. In 1925 all

varieties used on tree 406-5 failed to set fruit. The normal set of open pollinated fruits was low. Delicious flowers selfed on tree 406-7 produced no fruits. McIntosh pollen was very effective.

In 1926 all flowers on tree 279 (Table 13) were left exposed following emasculation. The Jonathan pollen, previously tested as to its viability, gave excellent germination. Fruits, however, failed to develop regardless of the position of the flowers.

At Hamden (Table 14) fruits failed to develop from any of the varieties used as pollinizers. The open-pollinated flowers on trees 2, 5, 49, and 60 fell at the first drop without setting fruit.

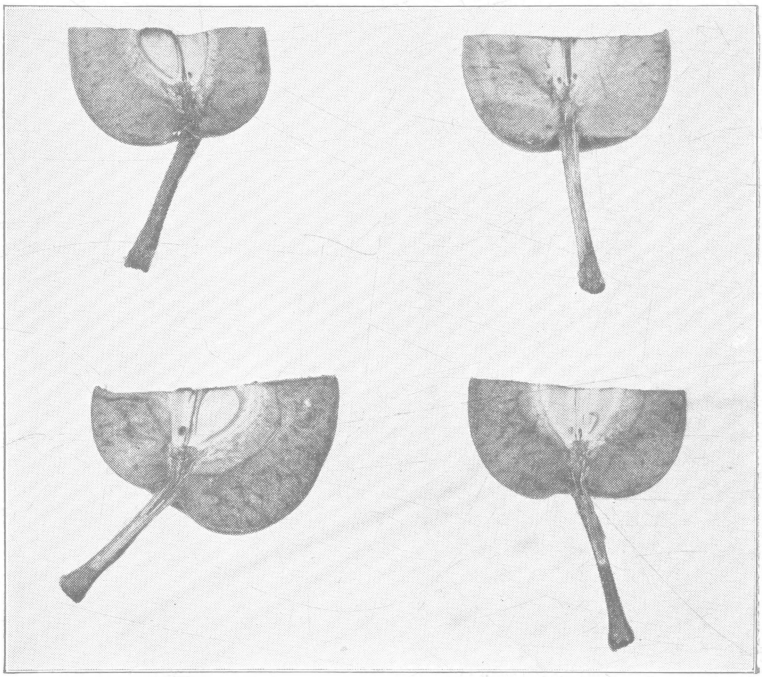

Fig. 8.—Developing Baldwin fruits from selfed tree cut to show entire seed content

Note only two fruits with an apparently normal seed.

The failure of Delicious to give satisfactory percentages of set from hand pollinated flowers appears unrelated to bagging. It is probable that emasculation was a factor in decreasing the set. However, the low normal set of open-pollinated flowers indicates that a considerable number were unable to set fruit even when pollinated by effective varieties.

TABLE 13.—Pollination of Delicious, Wooster

Pollen variety	Number of flowers pollinated	Percentage set
Tree 406-9, pollinated May 13 or 14 (†), 1924, flowers bagged		
Delicious†	38	2.6
Golden Delicious†	40	0
Grimes Golden	16	6.2
Stayman Winesap*	64	0
Open set**		
2 flowers	198	2
Tree 406-5, pollinated April 25, 1925, flowers bagged		
Grimes Golden	46	0
Ohio Nonpareil*	84	0
Rhode Island Greening*	152	0
Open set		
Entire cluster	508	3.7
2 flowers	200	7.5
Tree 406-7, pollinated April 25, 1925, flowers bagged		
Delicious	162	0
Jonathan	178	0
McIntosh	106	23.6
Open set		
Entire cluster	655	14.2
2 flowers	220	27.3
Tree 279, pollinated May 13 and 14, 1926, flowers open		
Jonathan††	304‡	0.7
Jonathan	286§	0
Open set		
Entire cluster	492	12.6

*Pollen of very low germinability.
**Set on tree very unsatisfactory on many limbs; fair on others. First drop very heavy.
††Pollen collected May 10 and 11 from Jonathan tree 407.4.
‡One central and one lateral flower pollinated in each cluster.
§Two lateral flowers pollinated in each cluster.

TABLE 14.—Pollination of Delicious, Hamden

Pollinated May 28, 1924, Flowers Bagged

Tree No.	Pollen variety	Number of flowers pollinated	Percentage set
1	Jonathan	62	0
	Open set		
	2 flowers	120	4.2
2	Jonathan	66	0
	Open set	.....	Unsatisfactory
3	Jonathan	28	0
	Grimes Golden	122	0
	Open set		
	2 flowers	20	15.0
4	Jonathan	18	0
	Open set		
	2 flowers	111	11.7
5	Delicious	176	0
	Open set		
	2 flowers	20	0
49	Grimes Golden	58	0
	McIntosh	14	0
	Open set	.....	Unsatisfactory
60	McIntosh	36	0
	Open set	.....	All flowers abscised

ENSEE

Ensee flowers selfed at Wooster in 1924 and 1925 (Table 15) produced no fruits. Delicious, Golden Delicious, McIntosh, and Rome Beauty were effective pollinizers. Attention is called to the high percentage of set of the three latter varieties on tree 411-1. The relatively slight value of Jonathan as a pollinizer was probably accounted for by the very low viability of its pollen in all tests. In 1925 Rhode Island Greening and Ohio Nonpareil, as expected, were not effective pollinizers, while the normal set of open pollinated flowers was excellent.

TABLE 15.—Pollination of Ensee, Wooster

Flowers Bagged

Pollen variety	Number of flowers pollinated	Percentage set
Tree 411-1, pollinated May 9 and 10 (†), 1924		
Ensee*	84	0
Delicious	40	7.5
Golden Delicious†	94	36.2
Grimes Golden	78	5.1
Jonathan*	57	0
McIntosh†	42	66.7
Rome Beauty†	86	37.2
Open set		
Entire cluster	190	17.9
Tree 411-3, pollinated May 9, 1924		
Delicious	44	9.1
Jonathan*	32	3.1
McIntosh	56	48.2
Open set		Excellent
Trees 411-1-3, pollinated April 25, 1925		
Ensee*	90	0
Rhode Island Greening*	104	0
Ohio Nonpareil*	116	0
Open set		
Entire cluster	424	34.4
2 flowers	302	58.3

*Pollen of very low germinability.

GOLDEN DELICIOUS

HAND POLLINATIONS OF SELFED FLOWERS

Golden Delicious flowers selfed at Wooster in 1925 and 1926 (Table 16) produced no fruits. Gallia Beauty was an effective pollinizer.

TREE UNDER FRAME

Golden Delicious tree 396, next to Baldwin tree 395 (Fig. 6), was enclosed under a frame with a hive of bees the morning of May 7, 1926. The covering was from the same lot of material used to enclose Baldwin tree 395. No flowers had opened in the vicinity.

TABLE 16.—Pollination of Golden Delicious, Wooster

Flowers Bagged

Tree No.	Pollen variety	Number of flowers pollinated	Percentage set
	Trees pollinated April 25, 1923		
1—3	Golden Delicious	66	0
	Baldwin*	24	0
	Open set		Excellent
	Trees pollinated May 15, 1926		
1	Golden Delicious	84	0
	Delicious	8	0
	Gallia Beauty	10	0
	Open set		Excellent
2	Golden Delicious	62	0
	Open set		Excellent
3	Golden Delicious	54	0
	Gallia Beauty	12	33.3
	Open set		Excellent
4	Golden Delicious	10	0
	Open set		Excellent
5	Open set**		
	Entire cluster	120	22.5

*Pollen of very low germinability.
**After June drop.

The central flowers of Golden Delicious began to open on May 13. Branches of Baldwin, full of bloom, were placed in a pail of water in front of the hive on May 17, and in the center of the tree on May 19, the date of the beginning of full bloom on the tree. The anthers of the Baldwin flowers were beginning to dehisce. The weather following was very favorable for the bees, which were observed to be flying to and fro between the flowers of the two varieties.

TABLE 17.—Pollination of Golden Delicious, Wooster, 1926

Tree 396, enclosed with bees under frame with flowers of Baldwin

Number of flowers exposed to bees	1617
Number of fruits set June 12	43
Percentage set June 12	2.7
Number of flowers bagged and not exposed to bees	72
Fruits set under bags	0
Number of fruits at maturity, October 26	43
Percentage set at maturity, October 26	2.7
Average number of seeds per fruit	0.97
Average weight of fruit, pound	0.316

The 1617 flowers on the tree set 2.7 percent (Table 17). The low seed content of the fruits suggests the possibility that the fruits may have developed largely from selfed, rather than from cross-pollinated, flowers.

GRIMES GOLDEN

At Wooster in 1924 no fruits were obtained from selfing Grimes Golden; in 1925 1.8 percent set developed (Table 18). Baldwin, Ensee, and Rhode Island Greening pollen failed to give more than 5 percent germination, while Ensee pollen in all tests for the year failed to germinate. The sample of Jonathan pollen used on this tree was also of very low viability. Delicious, Golden Delicious, McIntosh, Rome Beauty, and Wealthy were effective pollinizers. In 1926 on tree 410-7 Baldwin and Rhode Island Greening gave small percentages of set, while Ohio Nonpareil produced no fruits. Delicious, Ensee, and Jonathan were very effective pollinizers. Ensee pollen in 1926 gave excellent germination in all samples. The differences in the percentage set between the bagged and open flowers with the exception of those pollinated by McIntosh are probably not significant.

TABLE 18.—Pollination of Grimes Golden, Wooster

Pollen variety	Exposure of flowers	Number of flowers pollinated	Percentage set
Tree 410—7, pollinated May 10 or 13,(†) 1924			
Grimes Golden	Bagged	92	0.0
Baldwin*†	Bagged	92	1.1
Delicious	Bagged	90	27.8
Ensee*	Bagged	102	0.0
Golden Delicious†	Bagged	96	50.0
Jonathan*	Bagged	92	3.3
McIntosh	Bagged	104	8.6
Rome Beauty†	Bagged	96	17.7
Wealthy	Bagged	86	9.3
Open set**			
2 flowers		260	2.7
Tree 410—9, pollinated April 25, 1925			
Grimes Golden	Bagged	56	1.8
Rhode Island Greening*	Bagged	68	3.0
Open set			
Entire flower		597	38.0
2 flowers		300	42.3
Tree 410—7, pollinated May 15, 1926			
Baldwin*	Bagged	70	1.4
	Open	62	3.2
Delicious	Bagged	54	37.0
	Open	44	34.1
Ensee	Bagged	44	61.4
	Open	58	55.2
Jonathan	Bagged	10	30.0
	Open	10	40.0
McIntosh	Bagged	38	39.5
	Open	32	21.9
Ohio Nonpareil*	Bagged	56	0.0
Rhode Island Greening*	Bagged	56	1.8
	Open	52	3.8
Open set—entire cluster			
Before June drop		648	39.5
After June drop		648	14.5

*Pollen of very low germinability.
**Limbs taken as checks had unsatisfactory set; set on tree as whole good.

At Hamden in 1924 (Table 19) selfed Grimes Golden flowers produced no fruits. The remainder of the data were rather unsatisfactory. Baldwin, as expected, produced no fruits and Delicious and McIntosh were of little value. Jonathan was an effective pollinizer.

JONATHAN

At Wooster in 1924 and 1925 selfed flowers of Jonathan (Table 20) failed to set fruit. Rhode Island Greening and Stayman Winesap pollen resulted in small percentage sets. Delicious, Golden Delicious, Grimes Golden, and McIntosh were effective pollinizers.

At Hamden in 1924 (Table 21) no fruits were produced from selfed flowers. Baldwin failed to be an effective pollinizer on any tree during the three years of the experiments. Delicious, Grimes Golden, McIntosh, and Yellow Transparent were very effective pollinizers.

The reason for the difference between the set of fruit on the uncovered and bagged flowers in 1926 is not known. It is possible that the exposed flowers dried out following emasculation.

McINTOSH

The small number of selfed flowers of McIntosh at Hamden in 1924 (Table 22) produced no fruits. Baldwin was of little or no value as a pollinizer. Delicious, Grimes Golden, and Jonathan were effective pollinizers. The percentage set of Grimes Golden pollen on tree 15 was not significantly different from that of the open-pollinated two-flower clusters.

NERO

The young trees of Nero at Hamden in 1924 (Table 23) failed to give a satisfactory set of fruit, either from the hand-pollinated flowers or those exposed to insect visitation. Grimes Golden was the only variety used as a pollinizer which produced fruit either on these trees or on the mature tree at Wooster in 1925.

NORTHERN SPY

Northern Spy flowers selfed (Table 24) failed to produce fruits. In 1924 Delicious and Jonathan were effective pollinizers. Baldwin, Stayman Winesap, and Grimes Golden failed to produce fruits. Golden Delicious, Rome Beauty, and Wealthy were effective pollinizers. In 1925 Delicious was an effective pollinizer. Baldwin, Rhode Island Greening, and McIntosh did not produce fruits.

TABLE 19.—Pollination of Grimes Golden, Hamden

Flowers Bagged

Tree No.	Pollen variety	Number of flowers pollinated	Percentage set
	Trees pollinated May 27 and 31(†) 1924		
25	Grimes Golden	26	0
	Open set		Satisfactory
21	Grimes Golden	48	0
	Open set		Satisfactory
14	Grimes Golden	10	0
	Delicious	92	2.1
	Open set		
	Entire cluster	86	64.0
	2 flowers	200	79.0
20	Jonathan	92	9.8
	Open set		Satisfactory
24	Jonathan	24	8.3
	Open set		Satisfactory
27	Jonathan	72	29.2
	Open set		Satisfactory
31	Baldwin*	70	0
	Open set		
	Entire cluster	69	33.0
57	Baldwin*†	30	0
	Open set		
	2 flowers	94	36.2
23	Delicious	102	1.0
	Open set		Satisfactory
34	McIntosh	208	0
	Open set		Satisfactory

*Pollen of very low germinability.

TABLE 20.—Pollination of Jonathan, Wooster

Pollen variety	Number of flowers pollinated	Percentage set
Tree 408-7, pollinated May 10(†), 13 and 14(††), 1924		
Jonathan ††	28	0.0
Delicious	88	24.0
Golden Delicious	38	68.4
Grimes Golden†	84	13.1
Stayman Winesap*	96	3.1
Open set**		
2 flowers	160	14.4
Tree 408-8, pollinated April 25, 1925		
Jonathan	60	0.0
Rhode Island Greening*	100	1.0
McIntosh	92	19.6
Open set**		
Entire cluster	337	32.0

*Pollen of very low germinability.
**After June drop.

TABLE 21.—Pollination of Jonathan, Hamden

Tree No.	Pollen variety	Exposure of flowers	Number of flowers pollinated	Percentage set
	Trees pollinated May 30, 1924			
46	Jonathan	Bagged	86	0
	Yellow Transparent	Bagged	100	22.0
	Delicious	Bagged	46	32.6
	Open set			Satisfactory
48	Delicious	Bagged	52	34.6
	Open set			Satisfactory
47	Delicious	Bagged	20	20.0
	Open set			Satisfactory
53	Baldwin*	Bagged	40	0
	Open set 2 flowers		50	20.0
55	Baldwin*	Bagged	56	0
	Open set			Satisfactory
45	Grimes Golden	Bagged	84	45.2
	McIntosh	Bagged	28	17.0
	Open set			Satisfactory
54	McIntosh	Bagged	14	57.2
	Open set			Satisfactory
51	McIntosh	Bagged	44	50.0
	Open set			Satisfactory
	Trees pollinated May 9, 1925			
1	Baldwin*	Bagged	78	0
	McIntosh	Bagged	88	10.2
	Open set Entire cluster		528	5 7
	Trees pollinated May 22, 1926			
2	Baldwin*	Bagged	72	0
		Open	122	0
	Delicious	Bagged	26	73.1
		Open	124	4.0
	Open set Entire cluster		430	4.0
3	Baldwin*	Bagged	14	0
		Open	40	0
	Delicious	Bagged	16	31.3
		Open	3)	0
	Open set Entire cluster		272	4.8

*Pollen of very low germinability.

TABLE 22.—Pollination of McIntosh, Hamden

Pollinated May 27, 1924, Flowers Bagged

Tree No.	Pollen variety	Number of flowers pollinated	Percentage set
39	McIntosh	48	0
	Open set		Satisfactory
32	Baldwin*	62	0
	Open set		
	2 flowers	154	42.2
35	Baldwin*	16	6.7
	Open set		Satisfactory
34	Delicious	42	26.2
	Open set		Satisfactory
16	Delicious	50	28.0
	Grimes Golden	22	36.3
	Open set		Satisfactory
26	Jonathan	14	7.1
	Open set		
	Entire cluster	219	15.5
	2 flowers	136	15.4
19	Jonathan	8	37.5
	Open set		Satisfactory
40	Jonathan	50	40.0
	Open set		Heavy
28	Jonathan	8	25.0
	Open set		Satisfactory
22	Jonathan	10	30.0
15	Grimes Golden	66	60.6
	Open set		
	Entire cluster	95	26.3
	2 flowers	200	71.5

*Pollen of very low germinability.

TABLE 23.—Pollination of Nero

Flowers Bagged

Tree No.	Pollen variety	Number of flowers pollinated	Percentage set
Trees pollinated May 30, 1924—Hamden			
44	Nero*	50	0
	Open set		Very poor
43	Nero*	56	0
	Open set		Very poor
42	Baldwin*	88	0
	Grimes Golden	84	8
	Yellow Transparent	94	0
	Open set		Very poor
41	Delicious	88	0
	Jonathan	92	0
	McIntosh	76	0
	Open set		
	Entire cluster	100	2.0
	2 flowers	200	4.5
Tree pollinated April 25, 1925—Wooster			
362	Grimes Golden	68	11.7
	Open set		
	Entire cluster	970	5.7
	2 flowers	88	20.4

*Pollen of very low germinability.

TABLE 24.—Pollination of Northern Spy, Wooster

Flowers Bagged

Tree No.	Pollen variety	Number of flowers pollinated	Percentage set
Trees pollinated May 16, 1924			
167	Northern Spy	50	0
	Baldwin*	44	0
	Delicious	56	50
	Grimes Golden	40	0
	Jonathan	42	52.4
	Stayman Winesap*	12	0
	Open set		Satisfactory
169	Golden Delicious	38	36.8
	Rome Beauty	86	31.4
	Wealthy	88	23.9
	Open set		Satisfactory
Tree pollinated April 28, 1925			
167	Baldwin*	92	0
	Delicious	20	20
	McIntosh	18	0
	Rhode Island Greening*	36	0
	Open set		
	Entire cluster	120	20

*Pollen of very low germinability.

OHIO NONPAREIL

Selfed flowers of Ohio Nonpareil failed to develop fruits (Table 25). In 1925 Delicious and Jonathan proved to be effective pollinizers. The percentage set of open-pollinated flowers was low compared to the set of the hand-pollinated flowers. In 1926 all varieties used as pollinizers failed to set fruit while the normal set again was low. Ohio Nonpareil is known only as moderately productive variety, altho it produces flowers abundantly.

TABLE 25.—Pollination of Ohio Nonpareil, Wooster

Flowers Bagged

Pollen variety	Number of flowers pollinated	Percentage set
Tree 183, Pollinated April 23, 1925		
Ohio Nonpareil*	96	0.0
Delicious	102	20.6
Jonathan	96	16.7
Open set		
Entire cluster	456	0.7
2 flowers	138	2.8
Tree 183, Pollinated May 10, 1926		
Baldwin*	110	0.0
Delicious	166	0.6
Oldenburg	103	0.0
Rhode Island Greening*	70	0.0
Open set		
Entire cluster	428	5.6

*Pollen of very low germinability.

OLDENBURG

Baldwin, Rhode Island Greening, and Grimes Golden were of little or no value as pollinizers (Table 26). The sample of Grimes Golden pollen used also did not germinate satisfactorily on sugar-agar media. Delicious and Wealthy were very effective pollinizers.

TABLE 26.—Pollination of Oldenburg, Wooster

Flowers Bagged

Pollen variety	Number of flowers pollinated	Percentage set
Tree 383, pollinated May 11, 1926		
Baldwin*	58	0‡
Delicious	66	39.4
Open set**		
Entire cluster	209	64.6
Tree 132, pollinated May 10 and 12,(†) 1926		
Baldwin*	8	0
Grimes Golden*	8	0
Rhode Island Greening*†	110	0‡
Wealthy	56	66.1
Open set		
Entire cluster	509	9.8

*Pollen of very low germinability.
**After June drop.
‡Baldwin 3 fruits and Rhode Island Greening 2 fruits not included, small, yellow, enlarged over petal fall stage, falling.

RHODE ISLAND GREENING

Rhode Island Greening flowers selfed (Table 27) failed to develop fruit. Baldwin and Ohio Nonpariel were of no value as pollinizers. In 1925 Jonathan and McIntosh proved to be effective pollinizers while Delicious set only 4 percent. In 1926 flowers pollinated by McIntosh and left uncovered gave a satisfactory set. Wealthy pollen failed to produce fruits.

The set of open pollinated flowers before the June drop was not more than 13.8 percent. The variety, in general, was an unsatisfactory female parent in both years.

ROME BEAUTY

In 1924 (Table 28) 80 selfed flowers set 2.5 percent. Baldwin and Stayman Winesap, as expected, failed to be effective pollinizers. For some unknown reason Delicious pollen also failed to produce fruit. Grimes Golden, Jonathan, Northern Spy, and Wealthy were effective pollinizers. The normal set of open-pollinated flowers (2 flowers left) was not sufficient to produce a satisfactory crop. In 1925 Delicious was the only pollinating variety which produced

TABLE 27.—Pollination of Rhode Island Greening, Wooster

Pollen variety	Exposure of flowers	Number of flowers pollinated	Percentage set
Tree 229, pollinated April 25, 1925			
Rhode Island Greening*	Bagged	202	0.0
Delicious	Bagged	102	4.0
Jonathan	Bagged	184	17.9
McIntosh	Bagged	86	32.5
Ohio Nonpareil*	Bagged	112	0.0
Open set			
Entire cluster		1061	10.0
2 flowers		186	11.2
Tree 227, pollinated May 11, 1926			
Baldwin*	Bagged	70	0.0
	Open	44	0.0
McIntosh	Bagged	72	1.4
	Open	38	15.8†
Wealthy	Bagged	8	0.0
	Open	26	0.0
Open set-entire cluster			
Before June drop		281	13.8
After June drop		387	12.4

*Pollen of very low germinability.
†1 fruit not included—small, yellow, enlarged, falling.

TABLE 28.—Pollination of Rome Beauty, Wooster

Pollen variety	Exposure of flowers	Number of flowers pollinated	Percentage set
Tree 430, pollinated May 17, 1924			
Rome Beauty	Bagged	80	2.5
Baldwin*	Bagged	98	1
Delicious	Bagged	38	0
Golden Delicious	Bagged	42	4.8
Grimes Golden	Bagged	90	21.1
Jonathan	Bagged	86	11.6
Northern Spy	Bagged	88	34.1
Stayman Winesap*	Bagged	60	0
Wealthy	Bagged	90	16.7
Open set			
2 flowers left		256	3.1
Tree 430, pollinated April 27 and 28(!), 1925			
Baldwin*	Bagged	86	0
Gallia Beauty	Bagged	80	0
Golden Delicious†	Bagged	52	0
Delicious†	Bagged	92	4.3
Open set			
Entire cluster		86	5.8
Tree 430, pollinated May 18, 1926			
Gallia Beauty	Bagged	80	1.3
	Open	90	3.3
Golden Delicious	Bagged	96	53.1‡
	Open	106	21.7
Open set			
Entire cluster		455	27.9

*Pollen of very low germinability.
‡2 fruits not included—small, yellow, enlarged since petal fall stage, falling.

fruit. Baldwin, Gallia Beauty, and Golden Delicious pollen were not effective. The normal set of open-pollinated flowers was again low. In 1926 Gallia Beauty gave only small percentage sets. The bagged flowers pollinated by Golden Delicious set a considerably higher percentage than the exposed flowers. It is again possible that this difference was due to the drying out of the pistils of the uncovered emasculated flowers.

STAYMAN WINESAP

At Wooster in 1924 selfed flowers of Stayman Winesap (Table 29) failed to produce fruit. Grimes Golden was an effective pollinizer while Jonathan was of no value. In 1925 Delicious and Gallia Beauty were satisfactory pollinizers. Baldwin, Jonathan, McIntosh, Nero, and Rhode Island Greening failed to produce fruits. The normal set of open pollinated flowers was low.

TABLE 29.—Pollination of Stayman Winesap, Wooster

Flowers Bagged

Tree No.	Pollen variety	Number of flowers pollinated	Percentage set
	Tree pollinated May 10 (†) and 15, 1924		
374	Stayman Winesap*	70	0
	Grimes Golden	90	25.6
	Jonathan†	76	0
	Open set		Fair
	Tree pollinated April 25, 1925		
374	Delicious	100	7
	Jonathan	194	0
	McIntosh	98	1
	Rhode Island Greening*	156	0
	Open set**		
	Entire cluster	228	0
	Trees pollinated April 27, 1925		
E—4	Gallia Beauty	94	6.3
	Jonathan	18	0
	Nero*	96	0
	Open set		Satisfactory
8—3	Baldwin*	90	0
	McIntosh	70	0
	Open set		
	Entire cluster	372	5.4
	2 flowers	378	0.5

*Pollen of very low germinability.
**Good crop on tree. Check limbs poorly chosen.

At Hamden in 1924 (Table 30) Baldwin was of no value as a pollinizer. Grimes Golden and Delicious were fairly effective, while Jonathan, McIntosh, and Yellow Transparent gave unsatisfactory sets of fruit. The normal set of open-pollinated flowers was again low.

TABLE 30.—Pollination of Stayman Winesap, Hamden

Flowers Bagged

Tree No.	Pollen variety	Number of flowers pollinated	Percentage set
	Trees pollinated 26, 27 (†) and 30 (‡) 1924		
8	Baldwin*†	180	0.0
	Grimes Golden	182	4.9
	Open set		
	Entire cluster	113	2.6
	2 flowers	200	2.5
10	Jonathan	188	1.6
	McIntosh	188	0.5
	Open set		
	Entire cluster	....	Below 8
13	Delicious†	152	7.1
	Open set		
	Entire cluster	.....	Below 8
30	Yellow Transparent‡	44	2.3
	Open set		
	Entire cluster	90	5.6
	2 flowers	200	7.0

*Pollen of very low germinability.

WEALTHY

No fruits developed from selfed flowers (Table 31). Baldwin was of little value as a pollinizer on tree 463 in 1924, but in 1926 the same tree produced 1.9 percent set from 52 bagged flowers and 9.4 percent from 32 uncovered flowers. This was the highest percentage set ever obtained with Baldwin as a pollinizer. On tree 291 in 1926 Baldwin failed to produce fruits. Nero and Ohio Nonpareil gave small percentages of set. Delicious, Golden Delicious, Grimes Golden, Jonathan, and Rome Beauty were effective pollinizers.

YELLOW TRANSPARENT

Baldwin and Rhode Island Greening (Table 32) were of no value as pollinizers, and Ohio Nonpareil was not sufficiently effective. Ensee, Jonathan, and San Jacinto were effective pollinizers. The percentage sets of the bagged Yellow Transparent flowers pollinated by these varieties were considerably higher than those of the uncovered flowers. It is possible that these differences were due to the drying out of the pistils of the uncovered flowers following emasculation.

TABLE 31.—Pollination of Wealthy, Wooster

Tree No.	Pollen variety	Exposure of flowers	Number of flowers pollinated	Percentage set
	Tree pollinated May 15 and 16(†), 1924			
463	Wealthy	Bagged	84	0
	Baldwin*	Bagged	88	1.1
	Golden Delicious†	Bagged	46	37.0
	Grimes Golden	Bagged	102	49.0
	Jonathan†	Bagged	98	33.7
	Rome Beauty†	Bagged	58	34.5
	Open set			
	Entire cluster		246	21.1
	Tree pollinated May 15, 1926			
463	Baldwin*	Bagged	52	1.9
		Open	32	9.4
	Delicious	Bagged	28	89.3
		Open	28	92.9
	Open set—entire cluster			
	Before June drop		579	35.9
	After June drop		507	10.5
	Trees pollinated May 13, 1926			
290	Delicious	Open	22	31.8
	Nero*	Bagged	64	0
		Open	64	1.6
	Ohio Nonpareil*	Open	84	3.6
	Open set—entire cluster			
	Before June drop		839	36.5
	After June drop		839	8.6
291	Baldwin*	Bagged	136	0
	Grimes Golden	Bagged	90	12.2
	Open set			
	Entire cluster		758	23.0

*Pollen of very low germinability.

TABLE 32.—Pollination of Yellow Transparent, Wooster

Pollen variety	Exposure of flowers	Number of flowers pollinated	Percentage set
	Tree 84, pollinated May 13 and 14(†), 1926		
Baldwin*	Bagged	82	0‡
	Open	62	0
Ensee	Bagged	48	12.5‡
	Open	32	3.1
Jonathan	Bagged	36	63.9
	Open	64	15.6
Ohio Nonpareil*†	Open	75	3.9
Rhode Island Greening*	Bagged	24	0
	Open	60	0
San Jacinto	Bagged	68	75.0
	Open	60	20.0
Open set—entire cluster			
Before June drop		491	22.6
After June drop		491	17.5

*Pollen of very low germinability.

‡Baldwin 11 fruits and Ensee 8 fruits, not included—small, yellow, slightly enlarged over petal fall stage, 1-6 the size of developing fruits, all falling.

DISCUSSION OF THE DATA

FRUITFULNESS OF VARIETIES WHEN SELF-POLLINATED

Degree of Self-fruitfulness of Varieties

This study regarding the degree of fruitfulness of Baldwin, Delicious, Ensee, Golden Delicious, Grimes Golden, Jonathan, McIntosh, Nero, Northern Spy, Rhode Island Greening, Rome Beauty, Stayman Winesap, and Wealthy, leads to the conclusion that these varieties are not sufficiently self-fruitful to justify their being planted in locations where they would be left largely to self-pollination.

It is very probable, however, that each of these varieties will produce a number of fruits when self-pollinated. In the experiments selfed flowers of Baldwin (Table 8), Delicious (Table 13), Grimes Golden (Table 18), and Rome Beauty (Table 28) occasionally set a small percentage of fruit. There is reason to assume that trees of the other varieties will set at least a few fruits from selfed flowers under orchard conditions, even tho none were obtained from the relatively small number of flowers pollinated in these experiments.

Classifications in Degree of Self-fruitfulness

From the evidence available, either in the literature or from this study, the writer does not wish to divide the varieties into arbitrary groups based upon different degrees of self-fruitfulness. Consequently, no attempt has been made to classify them as either self-unfruitful or partially self-fruitful upon the basis of small differences in percentage set. Several attempts to do this in the past have been shown to have resulted in a number of apparent contradictions in the literature. Lewis and Vincent (52) classified varieties as self-fruitful when the set, for instance, was no more than 1.2 percent with Baldwin, 2.6 percent with Grimes Golden, 0.9 percent with Oldenburg, and 1.2 percent with Colvert. Sutton (70), Crane (17, 18), Vincent (72), and Rawes (65, 66) classified a variety as partially self-fruitful whenever one fruit was produced, regardless of the number of flowers pollinated. Furthermore, Sutton and Crane extended the upper range of the partially self-fruitful condition to approximately 4 percent. Confusion then arises when other investigators classify the same varieties as self-unfruitful following experiments in which they obtained similar small percentage sets from selfed flowers.

To be sure these investigators have not been misled by their own classifications and have concluded that the varieties in the partially self-fruitful group require cross-pollination for satisfactory commercial crops. Others, however, in reviewing the pollination literature have failed to appreciate the basis of such classifications and have considered that contradictions exist where, in fact, the data were very similar. They have occasionally cited the variation of the same variety among the different group summaries of various investigators as evidence to support the conclusion that marked differences in the degree of self-fruitfulness of that variety exist in these different localities. Arbitrary classifications of varieties into self-unfruitful and partially self-fruitful groups, upon the basis of the development of one or a few fruits, are hardly justified. If the development of a few fruits were to be the basis upon which a variety is to be considered partially self-fruitful, the writer would classify all varieties used in this study as partially self-fruitful in Ohio.

The problem, however, would not be solved. The varieties so classified would still not be sufficiently fruitful to give a satisfactory commercial crop if left to self-pollination. Recommendations based on the supposition that possibly one or two varieties may be sufficiently self-fruitful to set a profitable crop would be entirely unjustified. In some years under certain conditions a variety might possibly set a sufficient number of fruits, parthenocarpic individuals included, to give a fairly satisfactory crop. However, if we follow this possibility, with the conclusion that the variety may be planted in large blocks, we are far from being even reasonably certain that the light yields which may result are not due to inadequate cross-pollination.

It is not denied that the varieties used in this study classified as not sufficiently self-fruitful to give commercial crops, may be slightly unlike in degree of self-fruitfulness. That the variety Baldwin in Ohio, however, is self-fruitful to a greater degree than Grimes Golden, Jonathan, Rome Beauty, and Wealthy, for example, has not been indicated by any data in these experiments. No trees of other varieties were enclosed under frames with which to compare the results from the Baldwin tree. It is true that the Baldwin tree enclosed under the frame gave a fairly satisfactory crop, but the writer does not accept, for reasons given later, the data from this tree as indicating the degree of self-fruitfulness of this variety under orchard conditions in Ohio.

However, the evidence in the literature, and data obtained in various fruit setting studies in Ohio, indicate that Delicious, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap may possibly have a slightly smaller degree of self-fruitfulness than such varieties as Baldwin, Grimes Golden, Jonathan, Rome Beauty, and Wealthy. That another factor is concerned which may considerably accentuate this difference is probable (42).

Variations of Self-fruitfulness in Different Localities

It has been stated that the degree of self-fruitfulness of a variety varies from one locality to another, from one orchard to another. These variations have been assumed to be due to differences in the normal climatic and cultural conditions under which the trees were growing. It is not denied that varieties in different localities may differ in degree of self-fruitfulness. However, the differences that do exist do not appear to be so closely correlated with differences in the normal climatic or approved cultural conditions, in the different localities, as has often been assumed. Moreover, the conception that such marked differences in the fruitfulness of a variety exist between localities, as we are sometimes wont to believe, is not justified from a critical survey of the literature.

It is not denied that the degree of self-fruitfulness of a variety may vary from season to season. However, the data given in support of such variations usually have not been presented in sufficient detail and have not been accompanied by adequate discussion of the conditions of the trees and of the experimental procedure to permit a definite conclusion.

Methods of Determining Degree of Self-fruitfulness

A higher percentage set of flowers was obtained from the Baldwin tree enclosed under the muslin frame than was ever obtained from hand pollinated flowers of the same variety, whether bagged or left uncovered. Altho under orchard conditions a small percentage of set will develop from selfed flowers, it is not justifiable at present to assume that the proportion will be as large as that on the enclosed tree.

This difference between the results obtained from the two methods of self pollination, may give rise anew to certain objections to the use of bags as means of determining the degree of self-fruitfulness of a variety. Serious criticisms have been made (46, 11, 55) that bags used to enclose flowers cause abnormal and possibly harmful conditions of light intensity, humidity, and temperature.

It is assumed that this would result in a decrease in the number of fruits setting at the critical period following petal fall. Undoubtedly the conditions within the bags are abnormal. The light intensity is somewhat decreased even with transparent paper bags. The humidity in all probability is higher within the bags, while the temperature may be either higher or lower, depending upon the rapidity and degree of change in the outside temperature between night and day and during the day.

There is available considerable evidence in the literature, however, indicating that the use of paper bags (even of manila paper) in pollination experiments has not resulted in such harmful effects as theoretically might seem probable. Waite (74) obtained results from selfing flowers of Anjou pear with paper bags similar to those from the use of cheesecloth and mosquito net bags. Booth (9) stated that varieties which are recognized to be self-fruitful will frequently set no fruit at all under bags. In support of this conclusion he reported some experiments of Lowe and Parrott, in which a tree of the Ben Davis variety, declared by Booth to be self-fruitful, enclosed under a muslin frame, set only 5 fruits from 315 flowers. However, this result is in accordance with other experiments (52, 78, 72, 60, 67) which indicate consistently that Ben Davis is self-fruitful to a slight degree only. Thus, Booth's conclusion is not justified from his example. He also stated that muslin sacks gave the "same contradictory results as paper ones" and described experiments of Lowe and Parrott in which small trees or large branches were covered with muslin, and windows made of wire screen to admit light and air. In no case, reported Booth, did they obtain more fruit close to the windows than away and there was no more fruit in the sacks with windows than in those without. It is thus evident that even when the light was not appreciably decreased and when the humidity was probably little changed, no different results were obtained with Ben Davis than when bags were used. Furthermore, Lewis and Vincent (52) reported that they obtained results from the use of manila paper bags similar to those from fine and coarse cheesecloth bags.

An interesting light from another point of view is thrown upon the question of the effect of bagging. Harvey and Murneek (34) presented data indicating that a reduction in leaf surface to two leaves to a flower-bearing spur has little influence upon the number of fruits set after the first drop. This suggests that a slightly decreased light intensity for a period from a *day* or *two* before full bloom (when the flowers are bagged) until one to two weeks after

petal fall (when the bags are opened) might not have an appreciable effect upon the set of fruit of the two flowers of a cluster pollinated.

Unquestionably, the light intensity was considerably decreased by the use of manila paper bags used by a number of investigators. In this connection Heinicke (36) presented data to indicate a greater percentage of set under translucent bags than under brown opaque bags. However, it is well to remember that Heinicke bagged the flowers just as they were separating from one another and left them bagged until the June drop. In all pollination experiments the flowers are not bagged until within a day or two of full bloom, and the bags are opened up shortly after petal fall.

Moreover, it has been observed in these experiments that the percentage set was no higher when the bags were removed immediately after all danger from cross pollination was over than when the flowers remained enclosed in the bags two weeks longer.

There are several further lines of evidence which suggest that bagging in these experiments accounts for the differences in the results from the hand-pollinated flowers of Baldwin and those from the tree enclosed under the frame with bees. The data given by Sax (67) in which no flowers of Baldwin were bagged are very similar to those herein presented (Tables 8 and 9). The percentage set of bagged flowers pollinated by compatible varieties in a number of cases where comparisons are available, was considerably greater than the normal set (2 flowers left) of open-pollinated flowers on the same tree. For example: Baldwin flowers on tree 9 (Table 9) at Hamden, pollinated by Grimes Golden, set 65.7 percent, while the normal set of open-pollinated flowers (2 flowers left) was 42.0 percent. The comparative data obtained in 1926 from the bagged flowers and those of the same vigor left uncovered (Tables 8, 9, 18, 21, 27, 31, 32) give no indications that bagging decreased the percentage set. Altho the percentage set of the selfed Baldwin flowers left uncovered (Table 8) was 2.6, while no fruits were obtained under bags, the variations between the results for the compatible pollen varieties on Baldwin indicate that the range of variation without significance may be 5 to 10 percent.

The criticism may be advanced that the low set of hand pollinated Baldwin flowers might be due to emasculation. There is relatively little evidence in the literature to enable conclusions to be drawn as to whether emasculation, performed carefully and at the proper time, reduces the set. Limited data presented by Alderman (1) is available in this connection. The difference between the set of fruit from emasculated and non-emasculated selfed flowers of Rome Beauty and York Imperial did not appear to be significant.

The percentage sets of emasculated flowers of Rome Beauty and York Imperial, crossed with each other and with Wagener and Ben Davis, seemed to be considerably higher than those of the non-emasculated flowers. Overholser (61) stated that in California, emasculated flowers, not bagged, dry out. In several crosses in the experiments reported herein (Table 8, Baldwin; 18, Grimes Golden; 21, Jonathan; 32, Yellow Transparent) the emasculated flowers left uncovered did not give as high percentage sets as flowers left uncovered, even when the probable experimental error is considered. It is possible that the uncovered emasculated flowers dried out, while bagging largely if not wholly prevented such dessication. However, that emasculation accounts for the difference between the percentage set of selfed flowers under the two methods (Tables 8, 10) seems at present improbable to the writer.

At the present time the reasons for differences between the results from the use of bags and from the trees enclosed under frames with bees are unknown. The external and internal conditions of the flowers with the two methods are unquestionably dissimilar. The flowers under the frames were visited by the bees a great many times each day during the entire blooming season while the hand-pollinated flowers on the open-pollinated tree were self-pollinated only once. Whether more pollen would be applied to the flowers in the first case than in the second cannot be stated.

Moreover, what may be still more important is the probability that the nutritional conditions of the flowers with the two methods are unlike. Ewert (24, 25, 26) first suggested the idea that the nutritional rearrangements may be somewhat different on a tree when left entirely to self-pollination than when a relatively few flowers are self-pollinated and the remaining flowers exposed to open pollination. The higher set on the tree enclosed under the frame may be due in part to such differences in nutrition brought about by the failure of over 90 percent of the flowers on the selfed tree to develop after petal fall. With vigorous trees this failure of such a large proportion of flowers to remain after the first drop would likely result in an adequate supply of food, water, and mineral nutrients to the relatively few remaining fruits. These slightly developed fruits may then be able, together with the stimulus of fertilization in one or two ovules, to remain on the tree until maturity. Thus the redistribution of food material, following the heavy early drop of flowers, may influence few-seeded fruits to remain that would otherwise largely have fallen.

There was some suggestion that nutrition was of particular importance with the fruits setting on the tree enclosed under a frame. On the long vigorous shoots two or three fruits were developing from one cluster base. It is possible that the few seeded fruits on this tree (Table 10) would have fallen from the cluster base early in the season if they had been compelled to compete for food with cross-pollinated fruits having a larger number of seeds.

It thus appears to the writer that, even for nutritional reasons in self-pollination work, higher percentages of set may be expected from the method involving the enclosure of the trees under frames with bees than from the method involving the hand-pollination of flowers on *open-pollinated* trees. The evidence is not conclusive as to which method gives the degree of self-fruitfulness which would be present under normal orchard conditions. However, at the present time the writer believes that the conditions involved with the use of any method when *all* flowers on a tree are selfed, do not so closely approximate normal orchard conditions, where flowers on a tree are both *selfed* and *crossed*, as has been often assumed. In this connection it is well to remember that, because fruits are obtained by one method used to determine the degree of self-fruitfulness and not by another, the first method is not necessarily the proper one to use in pollination experiments. The second method which gives the fewer fruits may be more nearly similar to normal orchard conditions.

Field Observations in Determining Self-fruitfulness

Surveys, carefully planned to determine the degree of self-fruitfulness of a variety under field conditions, would give valuable information in regard to the fruitfulness of a variety in the season of the survey with which to compare the results obtained from the use of controlled methods. However, several points must be kept clearly in mind in interpreting results from the survey method. In a favorable season, bees will fly a considerable distance, probably one or two miles, making it possible to pollinate solid blocks of medium size with pollen from neighboring orchards. So-called "solid blocks" must not contain even one or two trees of another variety. Furthermore, the failure of certain varieties to set commercial crops under conditions in which other varieties give satisfactory yields may not necessarily be due to differences in degree of self-fruitfulness. Surveys to be of value for determining the self-fruitfulness of a variety, must be carried out over several years.

The data obtained during a season in which bee flight is continually limited to a few hundred yards will be of more value than data taken during a favorable blooming season.

Chandler (11) stated, as a result of field observations, that Rhode Island Greening fails to set fruit under conditions where Baldwin gives good crops. This fact has been considered to indicate that Rhode Island Greening is self-unfruitful and that Baldwin is self-fruitful. However, this difference may be due to other factors rather than to differences in the degree of self-fruitfulness of these varieties (42). The possibility of other factors entering in must be considered before differences in the fruit setting characteristics of two varieties in the field are necessarily charged to differences in their ability to set fruit from their own pollen.

EFFECTIVENESS OF VARIETIES AS POLLINIZERS

The varieties used in this study may be divided into two groups upon the basis of their effectiveness as pollinizers for other varieties. The first group is composed of those which were effective for all varieties upon which they were used, and the second group is composed of those which were of little value as pollinizers of any variety upon which they were used.

Effective Pollinating Varieties

The effective pollinating varieties were Delicious, Ensee, Golden Delicious, Grimes Golden, Jonathan, McIntosh, Northern Spy, Rome Beauty, San Jacinto, Wealthy, and Yellow Transparent. The writer does not feel justified, from the evidence at hand, to classify further any of these varieties based upon their relative effectiveness. Each was an effective pollinizer if its pollen in laboratory tests had given high percentages of germination and long pollen tubes (Fig. 9) and was used on a variety which had not given evidence that a considerable number of its flowers are unable to set fruit no matter by what variety pollinated.

Ineffective Pollinating Varieties

The varieties in the second group, which proved to be inadequate pollinizers for any variety, were Baldwin, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap. Banks was not a consistently effective pollinizer for Baldwin (Table 8), the only variety upon which it was used.

The data for Baldwin are in accord with those obtained by Gowen (32), Sax (67) in Maine, and Stout (69) in New York. The

data for Nero are similar to those obtained by Close (14). The results from Rhode Island Greening as a pollinizer confirmed those of Gowen (32), Sax (67), Vinson (73), and McDaniels (55). The work with Stayman Winesap corroborates that of previous investigators (14, 60, 2). Banks had not been used in previous pollination experiments but it appears to be of no more value as a pollinizer than Gravenstein (72, 32).

Altho, in the greater number of cases in these experiments, no fruits were obtained from these varieties as pollinizers, occasionally small percentages of set developed. However, these sets were insignificant compared to the percentages given by the effective pollinizers. Even tho it is justifiable to assume that pollen of these varieties is capable of producing some fruits, it cannot be concluded that they will give sufficiently high sets to warrant their use as pollinating varieties.

Effectiveness of Pollinizer and its Pollen Germination

Conclusive evidence indicating correlation between the germination of pollen of a variety in the laboratory and its effectiveness as a pollinizer in the orchard cannot be given in detail in this publication. The pollen of varieties which were not effective pollinizers gave very low percentages of germination in the laboratory tests on 10-percent sugar-agar media at 15, 20, 25, and 28° C. (Fig. 10). In no samples was the germination of Baldwin and Rhode Island Greening pollen over 7.5 percent, while as a rule it was considerably less. Samples of Nero, Ohio Nonpareil, and Stayman Winesap pollen gave less than 4 percent germination. The pollen tubes of these ineffective pollinating varieties which were found, were short, thick, and soon burst. The pollen of the effective pollinizers with the same media and identical conditions of light, temperature, and humidity gave high percentages of germination and long, thin, normal pollen tubes (Fig. 9).

Physiological Cross-incompatibility

No definite examples of physiological cross-incompatibility were observed. Gallia Beauty, a seedling of Rome Beauty, when used as a pollinizer of Rome Beauty was the only case in which a suggestion of this was obtained. Altho Gallia Beauty pollen gave excellent germination, it failed to set fruit on Rome Beauty both in 1925 and 1926 (Table 28). Further work is desirable with this combination before classifying the varieties concerned as physiologically cross-incompatible.

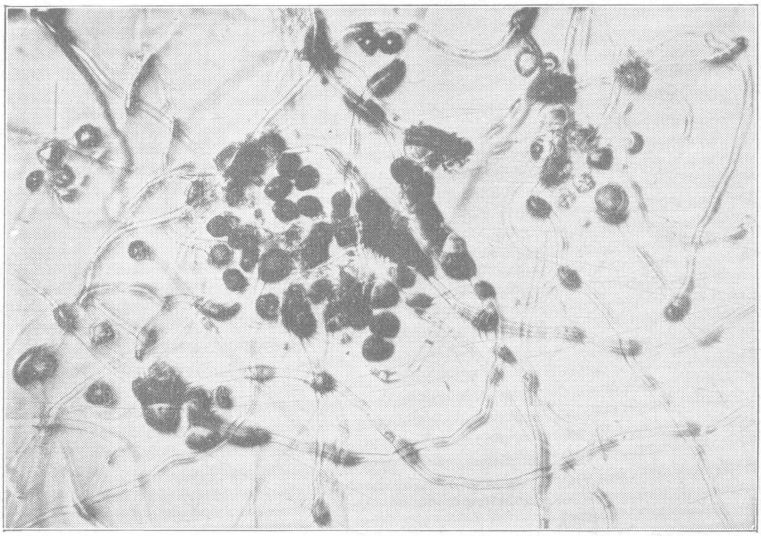

Fig. 9.—Germination of Delicious pollen on 10-percent agar-sugar media, after 60 hours May 27, 1926

Note abundant germination and long, narrow tubes

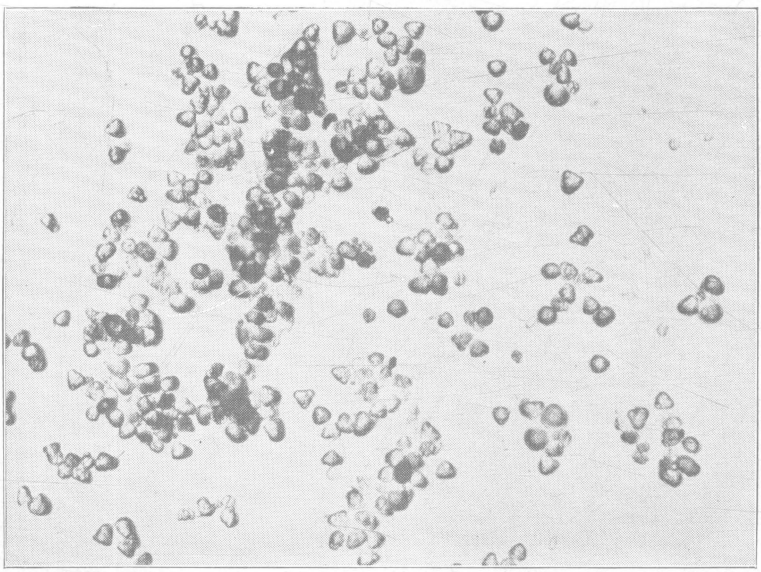

Fig. 10.—Germination of Baldwin pollen on 10-percent agar-sugar media, after 48 hours May 25, 1926

Note failure of practically all grains to germinate

Cross-sterility

In view of the correlation between the inability of the pollen of Baldwin, Banks, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap to give satisfactory percentages of germination and normal pollen tubes and their ineffectiveness as pollinizers it appears that this inter-unfruitfulness with other varieties is an example of cross-sterility due to impotence of pollen, intersexualism.

FRUITFULNESS OF VARIETIES AS FEMALE PARENTS

Before the failure of crosses to be fruitful can be charged to physiological cross-incompatibility resulting from close-relationships between varieties or other factors, there should be a more accurate understanding of the behavior of certain varieties as female parents, apart from their behavior as pollen parents. Such cases of inter-unfruitfulness may be the result of the impotence or weakness of the egg apparatus of the female parent rather than of incompatibility between normal sex elements.

Preliminary evidence indicating that Delicious, Rhode Island Greening, and Stayman Winesap and other members of the Winesap family have a considerable proportion of flowers unable to set fruit even when pollinated by an effective pollinating variety, was recently given (42). Further evidence in support of this conclusion is available from the experiments herein reported.

Emasculated and pollinated Delicious flowers on mature trees (Tables 13, 14), both bagged and left uncovered, largely failed to give satisfactory percentages of set. This agrees with the results reported by Dorsey (21) with emasculated uncovered flowers of Delicious in the greenhouse and with those of Auchter (2) and Haber (33) from emasculated, bagged flowers. Whitehouse and Auchter (77) recently obtained satisfactory percentages of set from unemasculated, hand cross-pollinated Delicious flowers on a tree under a frame. After due allowance has been made for the effect of emasculation or bagging or both, upon the set, the evidence indicates that a considerable number of flowers of Delicious are unable to set fruit even when pollinated by effective varieties. Delicious usually has a very heavy first drop of undeveloped flowers leaving one to three partially developed fruits to a cluster. Several of these fruits normally abscise shortly thereafter, thinning the tree to a still greater extent. In this connection, Ranker (64) pointed out that the variety is a decided "self-thinner".

The data from Rhode Island Greening (Table 27) were somewhat similar to those from Delicious. Rather unsatisfactory percentages of set were obtained from Delicious and Wealthy as pollinizers. The normal set of open pollinated flowers was low.

The failure of McIntosh pollen to give a satisfactory set of fruit when used to pollinate Rhode Island Greening in the experiments of Sax (67) and McDaniels (55) has been suggested as an example of true physiological cross-incompatibility. McIntosh at Wooster was an effective pollinizer for Rhode Island Greening (Table 27), while Wealthy failed to produce fruit on Rhode Island Greening in 1926.

The writer does not feel justified from these data in classifying Wealthy and Rhode Island Greening as physiologically cross-incompatible. In the light of the results of Waite (75), Gowen (32), Morris (60), Sax (67), and Vinson (73), as well as those presented here, it apears that the failure of varieties which have pollen of high germinability to give satisfactory percentage of set in hand-pollination experiments with Rhode Island Greening, may be largely due to the inability of a considerable number of flowers of this variety to set fruit no matter by what variety pollinated.

Nero (Table 23) and Ohio Nonpareil (Table 25) gave low percentage sets when pollinated by varieties generally known as effective pollinizers. The data for Nero confirm that given by Powell (63) and Close (14). These varieties are known as light bearers even tho they produce an abundance of flowers.

Stayman Winesap (Table 30, 31) also showed a low set of fruit when pollinated by effective pollinizers. This likewise supports pollination data previously given by several investigators (14, 5, 60, 21, 45) and apparently indicates that a considerable proportion of its flowers cannot set fruit no matter by what variety pollinated.

On the other hand, Baldwin, Ensee, Golden Delicious, Grimes Golden, Jonathan, Rome Beauty, Wealthy, and Yellow Transparent gave relatively high percentages of set when pollinated by effective varieties. This indicates that they do not have an appreciable number of flowers that cannot set fruit when pollinated by an effective pollinizer.

McIntosh and Northern Spy also gave high percentages of set when hand pollinated with effective pollinizers.

Cross-sterility

It seems to the writer that crosses in which Delicious, Nero, Ohio Nonpareil, Rhode Island Greening, and Stayman Winesap and other members of the Winesap family are concerned as female

parents, and which result in small percentages of set from effective pollinizers, should be considered examples of partial cross-sterility rather than of physiological cross-incompatibility. Further evidence in support of this conclusion is desirable.

It is true that Delicious, Rhode Island Greening and Stayman Winesap usually produce higher yields of fruit under orchard conditions. However, these yields occur in spite of the inability of this large proportion of the flowers to set fruit, and together indicate the relatively low percentage set required for a satisfactory commercial crop.

PRACTICAL CONSIDERATIONS

FACTORS CONCERNED WITH CHOICE OF POLLINATING VARIETIES

Effectiveness of Varieties

The variety planted as a pollinizer should be desirable commercially. The many effective pollinizers adapted to Ohio conditions make it unwise to plant other varieties unless they are specifically desired.

The commercial varieties of Ohio (31) recommended as effective pollinizers of other varieties are:

Delicious
Gallia Beauty
Grimes Golden
Jonathan
McIntosh
Northern Spy
Oldenburg
Red Rome Beauty
Rome Beauty
Starking
Wealthy
Winter Banana
Yellow Transparent

The commercial varieties of Ohio which cannot be depended upon as effective pollinizers are:

Baldwin
Ohio Nonpareil
Rhode Island Greening
Stayman Winesap

The following varieties are effective pollinizers:

Cox Orange
Early Harvest
Ensee
Golden Delicious
Maiden Blush
Red Canada
San Jacinto (Wilson Red June)
Sutton
Wagener
Williams
Wolf River

The following varieties of little commercial importance in Ohio are of little or no value as pollinizers:

Arkansas (Mammoth Black Twig)
Arkansas Black
Banks (Red Gravenstein)
Gravenstein
Nero
Winesap

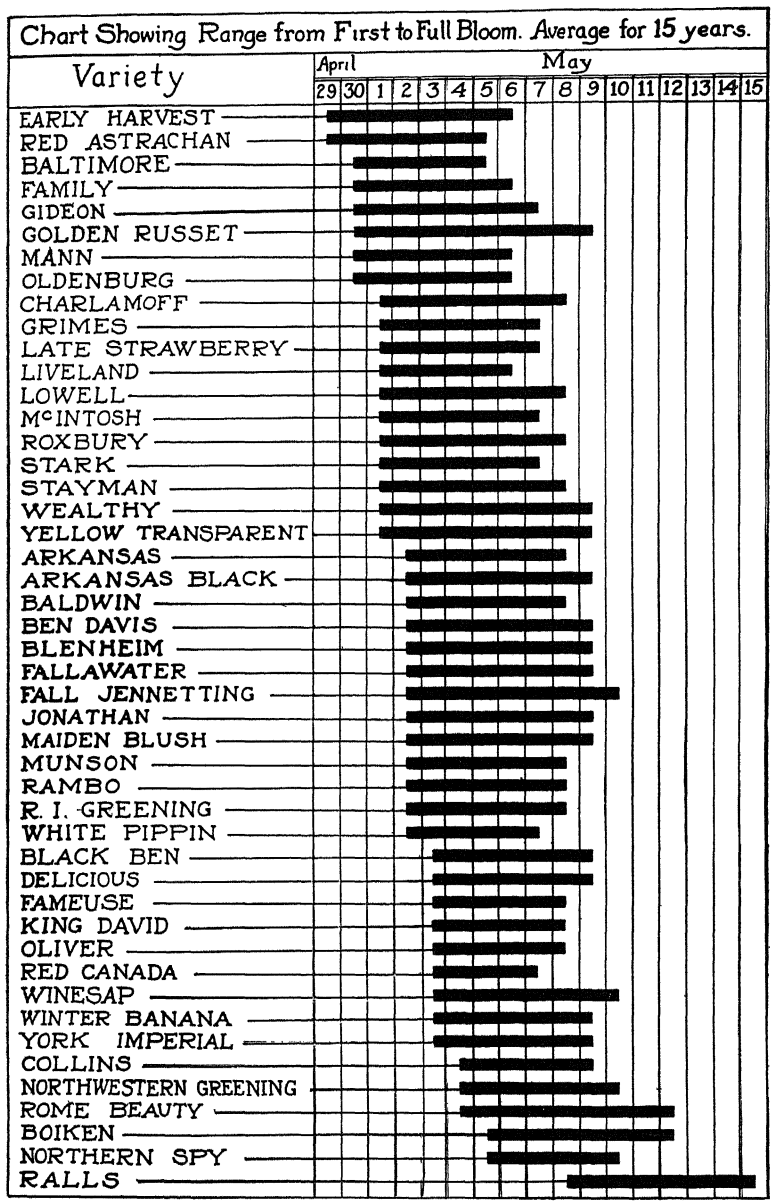

Fig. 11.—Chart showing range from first to full bloom—1910-1926, Wooster, Ohio

(From Ellenwood, 1925, Bul. 385)

Blooming Season

A variety planted as a pollinizer must have a blooming season that overlaps that of the variety or varieties it is intended to pollinate. This does not mean that the varieties concerned must reach full bloom at the same time. A variety cannot be an aid in pollination until its central flowers are open. The pistil of a flower is receptive shortly after it is exposed by the opening of the petals and probably continues to be receptive during a period ranging from two or three days to a week depending upon weather conditions and other factors. It is thus evident that the pollinating variety must have an appreciable number of its central flowers open before the pistils of the flowers of the variety to be pollinated have ceased to be receptive. It is possible, in seasons when the weather becomes unfavorable just at the time the variety to be pollinated has reached full bloom, that pollen of a late blooming variety intended as a pollinizer is of little value because of the failure of bee flight.

The blooming season at Wooster of the more common varieties of the State has been given by Ellenwood (23). Figure 11 presents the average range of first to full bloom of these varieties for 15 years. The blooming dates at Wooster are not identical with those of the same varieties in the extreme northeastern part or in the southern part of Ohio, altho the order of bloom is approximately the same. The number of days from first to full bloom varies with the weather conditions. Figure 11 indicates that all of the commercial varieties grown in the State, with the possible exceptions of Rome Beauty and Northern Spy, clearly have a sufficiently over-lapping blooming season to permit adequate cross-pollination of each other.

It has been generally considered that in some seasons Rome Beauty and Northern Spy may not be adequate pollinizers for earlier blooming varieties. Figure 11 indicates that over a period of 15 years Rome Beauty had its first bloom (a few central flowers open) approximately two days before full bloom with Oldenburg; three days before Grimes Golden and McIntosh; four days before Stayman Winesap, Baldwin, and Rhode Island Greening; and five days before Delicious, Jonathan, Winter Banana, and Yellow Transparent.

A further analysis of the relation of the blooming season of several of the earlier blooming commercial varieties to that of Rome Beauty is given in Table 33, which has been arranged to show the difference in days in each year, from 1911 to 1926, inclusive, between full bloom of these earlier blooming varieties and full

bloom of Rome Beauty. It is obvious that Rome Beauty cannot be a pollinizer of other varieties until its central flowers have started to open (first bloom); and in those seasons in which it fails to reach first bloom until after the greater number of the pistils of the flowers to be pollinated have passed the receptive stage, it will be of insufficient value as a pollinizer. The writer has arbitrarily considered that, in those years in which Rome Beauty did not reach first bloom until after the earlier blooming varieties had been in full bloom one day, it would have given unsatisfactory results as the only pollinizer. Unfavorable weather, beginning just as Rome Beauty reaches first bloom may entirely prevent it from being an effective and adequate pollinizer of an early blooming variety.

In 4 of the 15 years (Table 33) Rome Beauty did not open its central flowers until Oldenburg, the earliest blooming variety of commercial importance, had been in full bloom at least one day. In view of the arbitrary assumption already made, it is evident that Rome Beauty should not be depended upon as the only pollinizer of varieties which bloom as early as Oldenburg.

However, contrary to expectation it appears that Rome Beauty may be depended upon as the only pollinizer for Grimes Golden, Baldwin, Stayman Winesap, Yellow Transparent, Wealthy, Jonathan, and Delicious. It is possible however, that an occasional year may occur in which Rome Beauty will not bloom sufficiently close to these earlier blooming varieties to be an adequate pollinizer.

The question next arises as to whether Rome Beauty blooms too late to be adequately pollinated by earlier blooming varieties. Table 34, like Table 33, has been arranged to show the difference in days in each year from 1911 to 1926, inclusive, between the beginning of full bloom of Rome Beauty and of full bloom of several earlier blooming varieties. The lateral flowers of Rome Beauty obviously cannot be pollinated until they have opened (full bloom) and trees of the earlier blooming varieties serve as sources of pollen for a number of days after their flowers have reached full bloom. Just how long the pollen of a flower is available after the anthers dehisce cannot be stated. Depending somewhat on weather conditions, a tree should be able to furnish pollen for four or five days after reaching full bloom.

It is arbitrarily assumed that Rome Beauty would not be adequately pollinated in those years in which the earlier blooming variety had been in full bloom more than five days. By comparing the data relative to the beginning of full bloom of Rome Beauty with that of any earlier blooming variety, one can observe the

TABLE 33.—Relation of Date of First Bloom of Rome Beauty to Full Bloom of Earlier Blooming Varieties, 1911-1926, Wooster

Earlier blooming varieties	Number of years	Number of years first bloom of Rome after full bloom of earlier blooming varieties, in days					Number of years first bloom of Rome and full bloom of earlier blooming varieties coincident	Number of years first bloom of Rome before full bloom of earlier blooming varieties, in days									
		5	4	3	2	1		1	2	3	4	5	6	7	8	9	10 or more
Ohio Nonpareil	8		1			3	2	1				1					
Oldenburg	15	1		1		2	2	4	2	2		1					
McIntosh	16						4	4	4		3				1		
Grimes Golden	16						1	5	4	2	1	1	1		1		
Baldwin	16							5	2	5		2	1			1	
Yellow Transparent	15							6	3	1		1	2			1	1
Wealthy	16							5	4	1	2			2	1		1
Stayman Winesap	15							2	5	3	2	2					1
Jonathan	15						2	3	1	5	1	1	2				1
Delicious	16						1	2	3	5	3	1				1	

TABLE 34.—Relation of Date of Full Bloom of Rome Beauty to Full Bloom of Earlier Blooming Varieties, 1911-1926, Wooster

Earlier blooming varieties	Number of years	Number of years full bloom of Rome before full bloom of earlier blooming varieties	Number of years full bloom of Rome coincident with full bloom of earlier blooming varieties	Number of years full bloom of Rome after full bloom of earlier blooming varieties, in days									
				1	2	3	4	5	6	7	8	9	10
Oldenburg	15			1	1	3	1	3		1	1	3	1
Grimes Golden	16			1	3	5	4	1	2				
McIntosh	16			1	1	4	5	2	2			1	
Yellow Transparent	15	1	1	1	2	6	2		2				
Delicious	16		1		6	3	4	2					
Jonathan	16		1		6	5	2	2					
Wealthy	16		1	4	2	5	3	1					
Golden Delicious	4	1	2			1							

number of seasons that Rome Beauty did not reach full bloom until more than five days after full bloom in the earlier blooming variety. For instance, Rome Beauty did not reach full bloom until Oldenburg had been in full bloom six or more days in 6 years of 15, and Grimes Golden and Yellow Transparent 2 years of 16.

Varieties which bloom as early as Oldenburg must not be depended upon as the only pollinizers of Rome Beauty. In especially unfavorable blooming seasons Grimes Golden or Yellow Transparent, would probably not adequately pollinate Rome Beauty. In a normal season Rome Beauty should be adequately pollinated by the earlier blooming varieties, except Oldenburg, given in Table 34.

Golden Delicious blooms almost as late as Rome Beauty and is a very effective pollinizer of that variety.

The discussion concerning the blooming season of Rome Beauty should also apply to Gallia Beauty and Red Rome Beauty, and that of Delicious to Starking.

Time of First Flower Production

In choosing the pollinizers for a new planting the average age when flowers are likely to be first produced on the trees of the pollinating variety should be considered. This point, however, is of importance only during the first few crop years. Varieties used as pollinizers should begin to flower at approximately the same age as the varieties which they are to pollinate. Table 35 indicates the approximate age at which varieties have begun to bear at Wooster. It is evident that the combination of a variety in Class III with any variety in Class I would tend to be unfruitful until the variety in Class III had produced flowers. There would, however, be considerable overlapping between consecutive classes. As a rule the varieties in Class II should form their first flowers sufficiently near to those of Class I and Class III to act as pollinizers for varieties in those classes. It is also to be remembered that age of production of first flowers depends in part upon soil and cultural conditions. Young trees heavily pruned will be considerably delayed in the time of first flower formation.

Biennial Bearers

If two varieties only are to be planted, each of which is an effective pollinizer of the other, the combination may, in certain years, be unfruitful, if one or both of these varieties tend to be biennial bearers. Such an unfruitful combination would probably be Yellow Transparent and Wealthy. Another variety, preferably

TABLE 35.—Age at Which Varieties Have Reached Bearing at Wooster
From Ellenwood, 1925

Class I 8 years or less from planting	Class II 9 to 11 years from planting	Class III 12 years or more from planting
Baltimore	Baldwin	Northern Spy
Golden Delicious	Banks	Oliver (Senator)
Hubbardston	Delicious	Rhode Island Greening
Jonathan	Grimes Golden	
Oldenburg	McIntosh	
Stayman Winesap	Mother	
Wealthy	Rome Beauty	
Winter Banana	San Jacinto	
	Summer Rambo	

one bearing some flowers annually, should be planted to supplement Wealthy or Yellow Transparent. The importance of this precaution cannot be definitely stated since there may be sufficient flowers formed each year on trees of a variety that is a decided biennial bearer to serve as a source of pollen for the second variety, if plenty of bees are present in the orchard.

ARRANGEMENT OF POLLINATING VARIETIES FOR ADEQUATE CROSS-POLLINATION

New Plantings

Varieties intended as pollinizers, even tho of commercial importance, should not be scattered promiscuously thruout a new planting. Ease and convenience of spraying and harvesting demand that as many trees of a variety as can be adequately pollinized be planted together. No one can give the minimum number of trees of a pollinating variety relative to the trees to be pollinated. This varies from season to season depending upon such uncontrollable factors as sunshine, rainfall, temperature, wind, humidity, and such controllable factors as the number and distribution of bees in the orchard.

Pollination workers have usually advised that no more than four rows (160 feet) of one variety be planted together, followed by one to four rows of its pollinating variety or varieties, depending upon their desirability in the planting. Another arrangement might be two rows (80 feet) of a variety followed by two rows of its pollinating variety. More than four rows (160 feet) of one variety together would tend to prevent adequate cross-pollination in unfavorable blooming seasons when bee flight is limited to relatively short distances.

Whenever two varieties are planted together one only of which is capable of pollinating the other, a third variety is necessary to pollinate the second variety. Example: Jonathan would tend to be unfruitful in a planting of Jonathan and Stayman Winesap. A third variety, as Delicious, would be necessary to pollinate Jonathan because of the impotence of Stayman Winesap pollen and the low degree of self-fruitfulness of Jonathan. This third variety must be planted next to the variety which it is intended to pollinate. Figure 12 is a planting arrangment illustrating this point.

Trees No.	Rows 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
	Stayman Winesap				Jonathan				Delicious				Stayman Winesap				Jonathan			

Fig. 12.—Example of orchard arrangement showing location of third variety, when two varieties are to be planted, one only of which is capable of effectively pollinating the other

If only one row of pollinizers is desired following any variety, such as, Baldwin, Banks, Ohio Nonpareil, Rhode Island Greening, or Stayman Winesap that is not an effective pollinizer, at least two effective pollinizing varieties must be planted alternately in that row.

Young Trees

In an orchard recently planted in which effective pollinizing trees are partially or wholly lacking, the most convenient means of increasing the number of pollinating trees is to topwork trees at regular distances thruout the planting. It has usually been considered that every third tree in every third row should be sufficient to pollinate the planting effectively.

In young orchards of several varieties where the pollinating varieties have not produced flowers as yet, the bloom of several other varieties or of seedling apples may be introduced into the orchard each year until such trees do come into flowering (Fig. 13).

The bloom should be placed under or in trees to be pollinated. It is not desirable to place a large amount of bloom close to the hives in the orchard.

Fig. 13.—Distribution of bloom of several varieties of apple for pollination of Stayman Winesap Hamden Orchards, May 1925

The introduced flowers must be placed in tubs or pails of water as soon as the central flowers of the varieties to be pollinated have opened and a supply of pollen be kept available until several days after the beginning of full bloom. This may necessitate renewing the flowers once or twice during the blooming season, depending upon weather conditions and the amount of pollen available on the introduced flowers. Plenty of bees should be present in young orchards in which bloom is so introduced.

Mature Trees

In orchards of mature trees where it is suspected that fruit setting is limited by lack of an adequate number of pollinizers, top grafting as suggested under young trees is the most permanent means of insuring adequate pollination. Bloom may be introduced until flowers are produced by the top-grafted trees.

AGENTS OF TRANSFER OF APPLE POLLEN

Wind as Agent of Pollen Transfer

In 1925 at the Hamden orchards strips of celluloid 6 by 12 inches were covered with white vaseline and supported at heights of 4 to 10 feet from the ground. These were placed at distances varying from 3 to 20 feet from the trees. The celluloid strips were placed in the direct line of the prevailing wind for 24-hours exposure (12 noon to 12 noon) during which the conditions were ideal for pollination. They were then taken to the laboratory and immediately examined under the microscope. Pollen grains, if present, would have been easily recognized. No pollen was observed on any of the strips.

Moreover, in the pollination experiments, emasculated and self-pollinated, uncovered flowers set few or no fruits indicating that very little or no pollen was carried by the wind from trees of other varieti

It must be concluded from the evidence available at present from several sources that wind is of relatively little importance in the transfer of apple pollen.

Insects as Agents of Pollen Transfer

Honey bees are generally considered the principal carriers of apple pollen, altho other insects may be of some value. It has been observed that several species of bumble bee, wild bees, and various species of flies are often present in the orchards at blooming time. Bumblebees in some localities, where there is considerable waste land, may be particularly active during unfavorable weather when few honey bees are flying.

Distance Pollen is Carried

When the weather at blooming time is very favorable for bee flight, pollen may be carried in sufficient quantities for considerable distances. Just how far bees will fly is not known, altho apiarists state that bees will go from one to two miles to a source of pollen, if flowers are present in the intervening distance. It is evident that in seasons when the days are clear and warm relatively large blocks of one variety may be adequately cross-pollinated.

When the weather during the blooming season is unfavorable for insect flight, the set of fruit on trees of one variety will be influenced by the lack of adjacent trees of a pollinating variety. The

presence of sufficient bees in the orchard is particularly necessary at this time. The recommended planting arrangement of no more than four rows of a single variety is based upon the fact that in such seasons bee flight is limited to relatively short distances. In favorable years pollen will be carried much greater distances.

Number of Hives in the Orchard

It is rather difficult to determine how many hives are necessary in a planting for adequate pollination. The presence of wild bees, bumble bees and other minor pollen-carrying insects as well as honey bees in the vicinity may make necessary the presence of only a relatively few hives of honey bees in the orchards proper. More bees are needed as the trees become larger than during the first few years of bearing. When the trees are young (ten to fifteen years) one hive to three or four acres may be sufficient. With older trees one hive to one or two acres may be necessary for satisfactory commercial yields.

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